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ON TIDAL THEORY AND TIDAL PREDICTIONS.

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PREFACE.

The first part of this paper, containing a discussion of tidal theory, is to serve as an introduction to the second part, which will be given in a subsequent number of this JOURNAL, and will treat of a system of predicting tides, with especial reference to those at Cape Henlopen, Delaware Bay.

It is not intended here to render tidal theory in its completeness and all its details, nor is it intended to enter upon the various existing forms of it, excepting the one known as the Newtonian theory. With this as a basis the present theoretical discussion does not pretend to cover more than that ground only which is required for the distinct practical purpose in view.

The authorities consulted are:

1. *Newton.* Mathematical Principles of Natural Philosophy.
2. *Whewell.* Philosophical Transactions.
3. *Lentz.* Fluth und Ebbe des Meeres.
4. *Lubbock.* An Elementary Treatise on Tides.

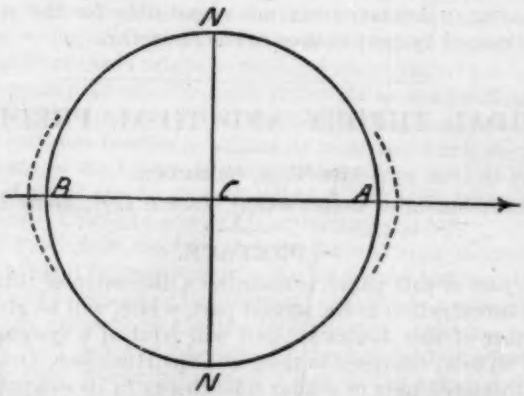
I. ON TIDAL THEORY.

Tides are caused by the difference in attraction exercised by Sun and Moon on those points of the Earth nearer to them, and on those points further from them.

Let us suppose the full circle in Fig. 1 to represent a section through the Earth's equator, and let us further suppose Sun and Moon both to

stand in the plane of the equator and in the direction of the arrow, then the point *A* being nearest to the heavenly bodies will be attracted strongest by them, the centre, *C*, somewhat further away, will be attracted somewhat less, and the point, *B*, still further away, will be attracted still less. If the entire mass of the Earth were rigid, these various attracting forces would simply result in a movement of *C*, or the entire mass of the Earth towards the attracting heavenly bodies, and in tensile strains at all points not situated in the plane, *N N*, such tensile strains being strongest at *A* and *B*, and thence gradually diminishing to nothing at *N N*.

FIG. 1

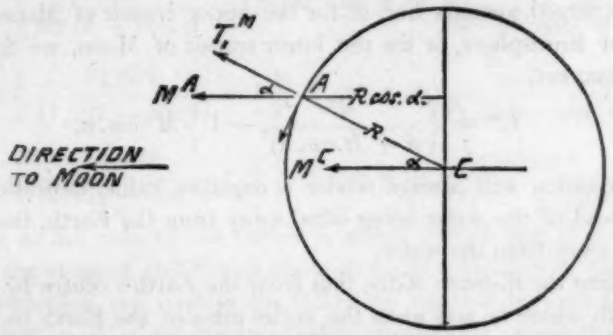


If now we suppose the Earth to be surrounded uniformly by water, then there will be no molecular force to resist these tensile strains and the particles of the liquid surface between *A* and the plane *N N* are free to follow their greater tendency of motion towards the attracting bodies, that is they will move towards them in advance of the entire mass of the Earth, such motion being greatest at *A* and thence gradually diminishing to nothing at *N N*. For the same reason the particles of the liquid surface between *B* and the plane *N N* are free to follow their lesser tendency of motion towards the attracting bodies, that is they will lag behind the entire mass of the Earth, such lagging behind being greatest at *B*, and thence gradually diminishing to nothing at *N N*.

This "moving ahead" of the water on the side turned towards the heavenly bodies, and this "lagging behind" on the side turned away from them, must result in accumulations of water on both sides, the

highest elevation of which must be situated at A and at B, in the direction of the heavenly bodies. The force, by the action of which these water mountains are raised is called the "tide-generating force" into the closer discussion of which we now proceed to enter.

FIG. 2.



Let us suppose the full circle in Fig. 2 to represent a section through the Earth's equator, the Moon to stand in the direction of the arrow M^c in the plane of the equator, and at the distance d from the Earth's centre, the Earth's radius to be R, and finally the directions of the attracting lunar force at the various points of our globe to be parallel amongst each other. If now the force with which the Moon acts at the Earth's centre be called M^c, and the force with which she acts at any given point, A, be called M^a, then we find according to the law of gravitation

$$\frac{M^a}{M^c} = \frac{d^2}{(d - R\cos.\, a)^2},$$

or,

$$M^a = M^c \frac{d^2}{(d - R\cos.\, a)^2}.$$

The difference

$$M^a - M^c = M^c \left\{ \frac{d^2}{(d - R\cos.\, a)^2} - 1 \right\},$$

shows the amount of lunar attractive force, which the particles of matter at A experience in excess of the force with which the centre or the entire mass of the Earth is attracted. Corresponding to the magnitude of such difference, therefore, the water at A will move ahead of the Earth in the direction to the Moon, and corresponding to the magnitude of the vertical component T_1^m of such difference, the water

will be vertically lifted. These vertical displacements of the water are the tidal phenomena, as we observe them, and the force

$$T_1^m = (M' - M^c) \cos. a = \left\{ \frac{d^2}{(d - R \cos.)^2} - 1 \right\} M^c \cos. a,$$

is therefore the lunar tide-generating force for that side of the Earth which is turned towards her, or for the upper transit of Moon. For the other hemisphere, or for the lower transit of Moon, we find in a similar manner,

$$T_2^m = \left\{ \frac{d^2}{(d + R \cos. a)^2} - 1 \right\} M^c \cos. a,$$

which equation will always render a negative value, indicating that here instead of the water being lifted away from the Earth, the Earth is lifted away from the water.

Denoting the distance of the Sun from the Earth's centre by D, the force with which he acts upon the entire mass of the Earth by S^c and his tide-generating forces by T_1^s for the upper and T_2^s for the lower transit, we thus derive, in precisely the same way as above,

$$T_1^s = \left\{ \frac{D^2}{(D - R \cos. a)^2} - 1 \right\} S^c \cos. a$$

$$T_2^s = \left\{ \frac{D^2}{(D + R \cos. a)^2} - 1 \right\} S^c \cos. a$$

Taking the Earth's diameter as a unit, we have, for the distances of Sun aud Moon, approximately

$$R = \tfrac{1}{2}, \quad d = 30{\cdot}13, \quad D = 11{,}567$$

and, introducing these values into our above equations, we now obtain for the tide-generating forces of Moon and Sun:

$$T_1^m = \left\{ \frac{(30{\cdot}13)^2}{(30{\cdot}13 - \tfrac{1}{2} \cos. a)^2} - 1 \right\} M^c \cos. a$$

$$T_2^m = \left\{ \frac{(30{\cdot}13)^2}{(30{\cdot}13 + \tfrac{1}{2} \cos. a)^2} - 1 \right\} M^c \cos. a$$

$$T_1^s = \left\{ \frac{(11{,}567)^2}{(11{,}567 - \tfrac{1}{2} \cos. a)^2} - 1 \right\} S^c \cos. a$$

$$T_2^s = \left\{ \frac{(11{,}567)^2}{(11{,}567 + \tfrac{1}{2} \cos. a)^2} - 1 \right\} S^c \cos. a$$

Developing the square in the denominator of the fraction, and then neglecting the very small $\frac{1}{4}\cos.^2 a$, we have

$$T_1^m = \left\{ \frac{30{\cdot}13}{30{\cdot}13 - \cos. a} - 1 \right\} M^\circ \cos. a = \frac{\cos.^2 a}{30{\cdot}13 - \cos. a} M^\circ$$

$$T_2^m = \left\{ \frac{30{\cdot}13}{30{\cdot}13 + \cos. a} - 1 \right\} M^\circ \cos. a = \frac{-\cos.^2 a}{30{\cdot}13 + \cos. a} M^\circ$$

$$T_1^s = \left\{ \frac{11{,}567}{11{,}567 - \cos. a} - 1 \right\} S^\circ \cos. a = \frac{\cos.^2 a}{11{,}567 - \cos. a} S^\circ$$

$$T_2^s = \left\{ \frac{11{,}567}{11{,}567 + \cos. a} - 1 \right\} S^\circ \cos. a = \frac{-\cos.^2 a}{11{,}567 + \cos. a} S^\circ$$

Now, as the mass of the Moon is about 0·0125 that of the Earth, and as the mass of the Sun is about 319,500 times that of the Earth, the Newtonian law renders the following relation between the forces M° and S°, with which the two bodies respectively attract the Earth,

$$S^\circ : M^\circ = \frac{319{,}500}{(11{,}567)^2} : \frac{0{\cdot}0125}{(30{\cdot}13)^2} = \frac{173{\cdot}43}{1}$$

that is to say, the solar attractive action on our globe is somewhat more than 173 times as strong as the lunar. Taking the lunar force as a unit, we can therefore subsitute in our equations

$$M^\circ = 1 \text{ and } S^\circ = 173{\cdot}431$$

and by doing so we obtain

$$T_1^m = \frac{\cos.^2 a}{30{\cdot}13 - \cos. a} \tag{1}$$

$$T_2^m = -\frac{\cos.^2 a}{30{\cdot}13 + \cos. a} \tag{2}$$

$$T_1^s = \frac{\cos.^2 a}{11{,}567 - \cos. a} 173{\cdot}431 \tag{3}$$

$$T_2^s = -\frac{\cos.^2 a}{11{,}567 + \cos. a} 173{\cdot}431 \tag{4}$$

which are the final expressions for the tide-generating force of Moon and Sun, T_1^m and T_1^s, as will be remembered, being that force for the upper transit of the attracting body, and T_2^m and T_2^s being that force for the lower transit of the attracting body. Now, as the height to

which the water is vertically lifted at each place stands in direct proportion to the tide-generating force acting at such place, we may also look on these equations as being expressions for the various altitudes of the lunar and solar wave above the low water plane. A scrutiny of the equations develops the fact that the value rendered by each of them is entirely dependent upon the value substituted for a, and, further, that in an absolute sense—that is apart from the algebraic sign—such value increases for a decreasing a, and *vice versa*. The angle a simply being the zenith distance at the terrestrial point in question of the attracting heavenly body, we find "that the amount of elevation caused by Moon or Sun at any given point on Earth is—apart from the variations in the distance of the heavenly bodies—entirely and solely dependent upon the zenith distance at the terrestrial point in question of the respective heavenly body, that it is the same for the same zenith distance, that it increases with a decreasing zenith distance, and that it decreases with an increasing zenith distance."

To find the relation between the lunar and the solar tidal elevations we divide equation (1) by equation (3) and equation (2) by equation (4), which will render, after a simple reduction,

$$\frac{T_1^m}{T_1^s} = \frac{11{,}567 - \cos.\, a}{(30{\cdot}13 - \cos.\, a)\, 173{\cdot}431} \qquad (5)$$

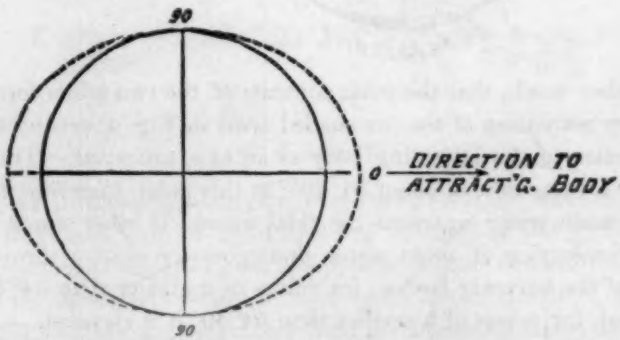
$$\frac{T_2^m}{T_2^s} = \frac{11{,}567 + \cos.\, a}{(30{\cdot}13 + \cos.\, a)\, 173{\cdot}431} \qquad (6)$$

The first four of these equations enable us to compute, for different values of the angle a, the tidal elevations caused by Moon and by Sun. The figures thus obtained, without representing any actual heights, will give the proportion the various lunar and solar ordinates bear to one another. The following table renders these figures, as computed for values of a from 10 to 10 degrees, and multiplied by 100,000, in order to avoid decimal fractions. It also renders the proportion in which each lunar ordinate stands to the corresponding solar ordinate, as computed from equations (5) and (6).

	Zenith distance, α.	Lunar ordinate.	Solar ordinate.	Proportions between lunar and solar ordinates.
Upper transit.	0°	3,433	1,500	2·289
	10°	3,328	1,454	2·288
	20°	3,025	1,324	2·285
	30°	2,563	1,124	2·279
	40°	1,999	880	2·271
	50°	1,401	620	2·262
	60°	844	375	2·251
	70°	393	175	2·239
	80°	101	45	2·226
	90°	0	0	2·214
Lower transit.	80°	99	45	2·201
	70°	383	175	2·189
	60°	816	375	2·178
	50°	1,343	620	2·167
	40°	1,900	880	2·159
	30°	2,419	1,124	2·152
	20°	2,843	1,324	2·147
	10°	3,117	1,454	2·144
	0°	3,212	1,500	2·143

The average proportion the lunar wave bears to the solar wave, as derived from this table, is equal to the proportions they bear to each other, for $\alpha = 90°$, viz., 2·214 : 1·000.

FIG. 3.

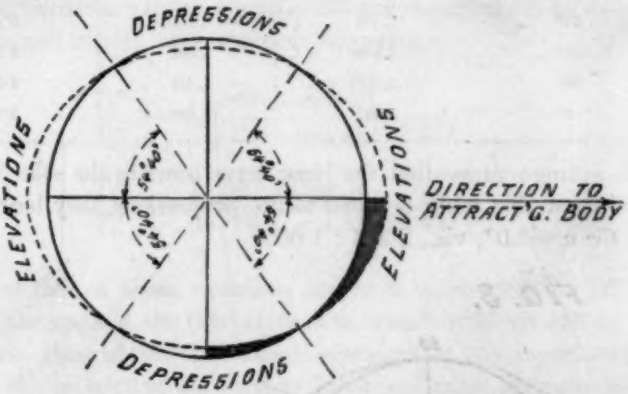


Let the full circle in Fig. 3 represent the low water circumference

of the Earth at the equator, or at any other great circle, and let the dotted ellipse represent the contour of the lunar or the solar wave. This ellipse coincides with the low water line at 90°, and thence gradually rises above it until at 0° and at 180°—that is, vertically under the attracting body—it has attained its highest elevations above low water.

If now, for a moment, we imagine the attraction of the heavenly bodies not to exist, then the water mountains formed by such attractions would speedily dissolve, the mass of water contained in them distributing itself around our globe at a certain uniform height above low water, or at a certain uniform distance from the Earth's centre. This imaginary surface of water, which would exist without the action of the heavenly bodies, is called the "Surface of Mean Water," and its position (which is shown by the full circle in Fig. 4) in regard to each wave must clearly be such that the cubic contents of the tidal elevations above it are equal in amount to the cubic contents of tidal depressions below it.

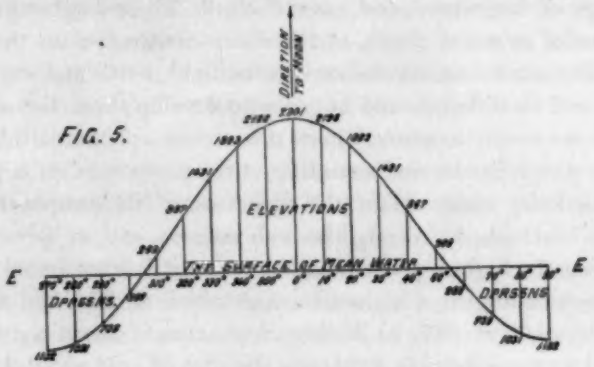
FIG. 4.



In other words, that the cubic contents of the two solids formed by an entire revolution of the two shaded areas in Fig. 4, around the line of direction to the attracting body as an axis, are equal. This is the case for a value of α of about 54°40′; at this point, therefore, the surface of mean water intersects the tidal waves; in other words, at this point the surface of mean water undergoes no change through the action of the heavenly bodies; for values of α greater than 54°40′ it is depressed, for values of α smaller than 54°40′ it is elevated.

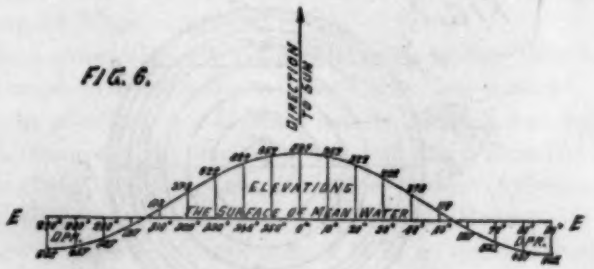
The diagrams, figs. 5 and 6 show the lunar and the solar wave in their proper positions relative to the mean water surface. Both heavenly bodies are supposed to stand in the plane of the equator and in the meridian 0°; the semi equator in both cases is developed into the straight line *EE* for the sake of clearer representation and the figures of elevation and depression are entered as derived from our table with reference to the surface of mean water. The corresponding figures for the waves incident on lower transits will of course be slightly different.

FIG. 5.



THE LUNAR WAVE

FIG. 6.



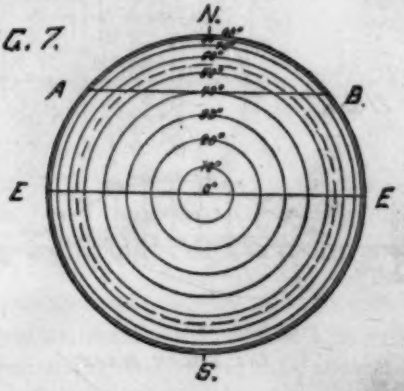
THE SOLAR WAVE

Fig. 7 represents the *lunar*, and *respectively the solar*, wave in its horizontal projection, each of them covering one-half of our globe. The *Moon*, and *respectively the Sun*, is supposed to stand vertically above the centre, the concentric circles around which are marked 10°, 20°, etc., according to their zenith distance from the attracting body; the dotted circle at 54°40′ is the neutral circle on the circumference of which

there is neither elevation above nor depression below the plane of mean water.

The point marked 0° is the point of highest elevation; the outer circle marked 90° is the circle of lowest depression or the circle of low water. Inside the neutral circle or the circle of mean water, the water is elevated, outside of it it is depressed, and these elevations above and depressions below the surface of mean water are the same along the circumference of one and the same circle, corresponding in each case to the figures of diagrams *5*, and, *respectively*, *6*. These diagrams and their figures refer, as stated above, to the component waves on the equator only. The conditions on the various latitudes north and south of the equator will be different, and in order to develop them for any given latitude, we simply examine where the various concentric tidal circles intersect such latitude and according to the position of such points of intersection we easily obtain the diagrams of its component waves. On Fig. 7 latitude 40° north has been entered, and we perceive at a glance that the highest point of each wave on it is contributed by circle 40°, corresponding to a highest solar elevation of 378, and a highest lunar elevation of 867, while the intersection of mean water surface and tidal wave on latitude 40° is at a distance of only about 41° longitude from such highest point.

FIG. 7.



The solar and the lunar wave, the generating of which we have discussed above, are constantly moving over the oceans independently of each other. The formation of one does in no way interfere with or modify that of the other, and the resulting tidal wave is created simply by a process of summation of the two component waves, a process that we can best picture to ourselves by imagining one of the component

waves laid on the top of the other. The most simple case of this process of summation takes place when Sun and Moon stand in the same direction; then the corresponding parts of the two waves will add themselves to each other; for instance the highest lunar elevation will rest on the highest solar elevation and the lowest lunar depression will stand under the lowest solar depression (Fig. 8). If Sun and Moon were always to stand in the same meridian, with an equal and constant declination, say, for instance, both always moving in the plane of the equator, then this would always be the way in which the two waves sum themselves. Both the Sun's and the Moon's tide-generating forces would then be united in the same direction, thus raising a resulting tidal wave the height of which would be equal to the sum of both component waves, being greatest at the equator, thence gradually diminishing towards north and south and finally running out into nothing at the poles. The circle of low water passing through the polar axis and hence always standing perpendicular on the plane of the equator as well as the planes of all other latitudes, would on every one of them divide the spaces between the two high waters into two equal parts each, that is, the duration of rise would everywhere be equal to the duration of fall, and thus each point on our globe under these circumstances would have two equally high high waters and two equally high low waters daily, the space of time intervening between them being six hours everywhere.

In reality, however, the heavenly conditions causing tides instead of being as simple and uniform as supposed above, are subject to constant changes, the principal ones of which may be designated as follows:

1. The changes in the distance of Sun and Moon from our globe;
2. The changes in the relative meridional position of Sun and Moon;
3. The changes in the declination of Sun and Moon.

We now proceed to discuss each of these as far as our subject requires it.

1. THE CHANGES IN THE DISTANCE OF SUN AND MOON FROM OUR GLOBE.

The Moon's orbit is an ellipse, one focus of which is occupied by the Earth, and during her revolution in this orbit the Moon therefore constantly changes her distance from our globe. The time occupied by one complete revolution of 360° around the Earth being measured by the Moon's return to the same fixed star, such revolution is called

"sidereal revolution," from the Latin "sidus," star. The sidereal revolution occupies about 27¼ days, and during this time we observe the Moon conforming to the above pass from her greatest distance to her smallest distance and back again to her greatest distance. Owing to the perturbing influence of the Sun, the extreme limits of the Moon's distance from us, that is to say, the semi great axis and the semi small axis of her orbit are not constant, but vary in a period of about nine years.

The earth's orbit is likewise an ellipse, one focus of which is occupied by the Sun, and during her revolution in this orbit the Earth therefore constantly changes her distance from the Sun, passing in the space of one year from her greatest distance (in summer) to her smallest distance (in winter) and back again to her greatest distance.

2. THE CHANGES IN THE RELATIVE MERIDIONAL POSITION OF SUN AND MOON.

If to-day Sun and Moon have culminated simultaneously, then to-morrow her own motion has carried the Moon about 12° east of the Sun and she will consequently culminate about 49 minutes after him; a day later she will stand about 24° east of the Sun, culminating about 1 hour 38 minutes later, and so on until after about 14¾ days she culminates 12 hours later than the Sun and finally after about 29½ days both heavenly bodies once more culminate simultaneously. This period of 29½ days elapsing between two conjunctions of Sun and Moon, inside of which we observe the Moon successively culminating in each of the 24 hours of the day, is called the "synodical month:" it would be equal in duration to the siderial revolution if the Earth merely rotated around its axis, without at the same time traveling around the Sun; but through the Earth's revolving around the Sun the position of the latter on the ecliptic is constantly shifting to the eastward and the Moon having after 27¼ days completed one sidereal revolution finds the Sun in a position so much more easterly that she has to travel about 2¼ days more before reaching his meridian, or as it was expressed above, before getting in conjunction with the Sun.

3. THE CHANGES IN THE DECLINATION OF THE SUN AND MOON.

The plane of the Earth's equator forms an angle of about 23½° with the plane of her orbit (ecliptic). Hence the varying declination of the Sun which is zero when our globe is at either point of intersection

between the equator and the ecliptic (vernal and autumnal equinox) and which thence gradually rises to about 23½° north or south when our globe is 90° from those points at the solstitials.

If the Moon's orbit were in the plane of the ecliptic, then it is clear that the limits of the lunar declination would be the same as those of the solar declination, viz., about 23½° north and south. In the period of one sidereal revolution the Moon would pass from 23½° declination on one side of the equator to 23½° declination on the other side, and thence return again to the original declination. The Moon's orbit, however, does not lie in the plane of the ecliptic, but is inclined to it somewhat more than 5° and according to the position of the lunar nodes (which is not fixed but revolving around the Earth) this inclination or part of it will either add to or subtract itself from the above angle to form the highest lunar declination for the time being. Such maximum lunar declination therefore ranges between about 18° and about 29°, and all the various stages of it are contained in a period of about 19 years, inside of which the nodes of the Moon's orbit complete their circle around the earth. At the time this is being written (beginning of October, 1884,) the maximum declination of the moon has its lowest possible value, somewhat more than 18°; it will now commence to increase and in about 9½ years will attain its highest limit, about 29°. At present, therefore (October, 1884), the Moon passes in the period of one sidereal month from a maximum declination of about 18° on one side of the equator, across the latter to about the same maximum declination on the other side and back again to the original declination.

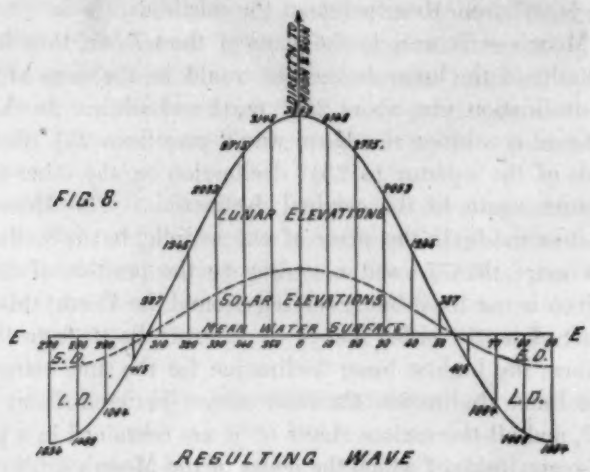
Having in the above discussed the peculiarities of the motion of the heavenly bodies as far as required for the final purpose in view, we now proceed to investigate their influence on tides.

THE INFLUENCE EXERCISED ON TIDES BY THE CHANGES IN THE RELATIVE MERIDIONAL POSITION OF SUN AND MOON, OR THE SEMI-MENSTRUAL INEQUALITY OF TIDES.

In order to find how tides are influenced by the above-described changes in the relative meridional position of the heavenly bodies we will start from the simultaneous culmination of both and the tidal wave created by it. Let the straight line in Fig. 8 represent the developed semi-equator on the surface of mean water and let the dotted

line be the solar wave, Sun and Moon standing in Meridian 0°, in the plane of the equator.

FIG. 8.



Now, by erecting our lunar elevations and depressions at the corresponding points of the solar wave, we obtain the resulting tidal wave (shown in a full line) described above, that is, the one having the highest range, which is called "Spring tide." It is evident that in this case the high water must be vertically under the two attracting bodies, because there the two highest elevations combine and it is also evident that in this case the low water must be 90° distant from the attracting bodies, because there the two lowest depressions combine. High water, therefore, in this case takes place simultaneously with the culmination of the heavenly bodies and low water takes place 6 hours 24½ minutes after it.

FIG. 9.

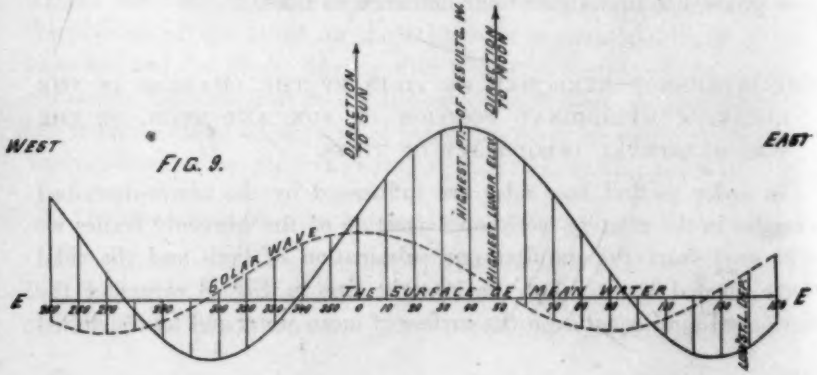
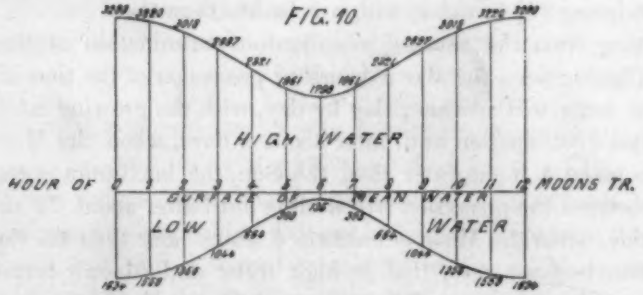


Fig. 9 represents the situation as it will be four days after the above, when the Moon culminates about 3 hours later than the Sun.

It is clear at once that the high water now must be lower and the low water must be higher than in the last case, because the extreme elevations and depressions of one wave now combine with the lesser elevations and depressions of the other wave. Thus the high water will continue to become lower and the low water will continue to become higher, with the growing lateness of the hour of the Moon's transit, the highest lunar elevations successively combining with lower and lower points of the solar wave, and the lowest lunar depressions successively combining with higher and higher points of the solar wave. Finally, about $7\frac{1}{2}$ days after the simultaneous culmination of the heavenly bodies, when the Moon culminates 6 hours later than the Sun, the highest lunar ordinate will combine with the lowest solar depression, there creating the lowest possible high water, and the lowest lunar depression will combine with the highest solar elevation, there creating the highest possible low water, which extreme case is called "Neap tide." Thenceforward the high water will again become higher and the low water lower, both once more reaching their maximum, the "Spring tide," after about $14\frac{3}{4}$ days, when Sun and Moon stand in opposition, that is, when the Moon culminates 12 hours after the Sun; then, as in the case represented in Fig. 8, the extreme elevations and depressions caused by one, once more combine with those caused by the other.



THEORETICAL CURVES OF SEMIMENSTRUAL INEQUALITY OF HEIGHT

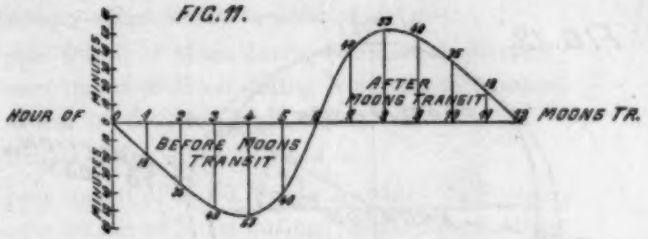
The half-monthly series of changes in the height of tides, above described, is represented in the diagram (Fig. 10), the figures of which refer to tides incident on upper transits.

The straight line is the surface of mean water, and on it are laid off the hours of Moon's culmination. Vertically to it, above and respectively below, are laid off the theoretical heights of high water, and, respectively, low water pertaining to each hour of culmination; the curves joining the points so obtained are called the curves of the semi-menstrual inequality of the height of high and low water.

Besides the *height*, the *time* of high and low water is also influenced by the varying meridional position of the Moon relative to the Sun. Let the conditions be exactly the same as those represented in Fig. 9, then the greater lunar elevation not standing any more on the highest point of the solar wave, but on a much lower one, is not able there to produce the highest point of the resulting wave. This will be created by a lunar ordinate, not much lower than the highest one, which, however, rests on a much higher point of the solar wave. The position of high water will thus be shifted from, vertically, under the moon to somewhat to the westward of it; that is, high water instead of taking place simultaneously with Moon's transit, will take place before it. The same deduction applies to low water. The lowest lunar depression combining with a comparatively high point of the solar wave is not able there to form the lowest point of the resulting tidal wave, but this will be formed by a lunar depression not much smaller than the lowest, which combines with a much lower point of the solar wave. The position of low water will thus also be shifted westerly, and the time interval elapsing between Moon's transit and low water, instead of being 6 hours 24½ minutes, will now be less than that.

Starting from the time of simultaneous culmination of Sun and Moon (Spring tide), the above described precession of the time of high and low water will increase, day by day, with the growing lateness of the Moon's culmination until after about 5 days, when the Moon culminates about 4 hours later than the Sun, the maximum is reached; thenceforward the precession will decline until after about 7¼ days, at Neap tide, when the Moon culminates 6 hours later than the Sun, the precession becomes zero, that is, high water and Moon's transit are once more simultaneous. Thenceforward high and low water will be retarded, such retardation reaching its maximum after about 10 days, when the Moon culminates about 8 hours later than the Sun; thenceforward it will decline until after about 14¾ days, at Spring tide, when Sun and Moon stand in opposition, it becomes zero, that is, high water and Moon's transit are again simultaneous.

Fig. 11. will serve to illustrate this series of half-monthly changes in the time of high and low water, as referred to the time of Moon's transit.



THEORETICAL CURVE OF SEMIMENSTRUAL INEQUALITY OF TIME

Vertically to the abscis-a, which represents the time of Moon's transit, are laid off the precessions and retardations theoretically pertaining to each hour of Moon's transit; the curve joining the points so obtained, is called the curve of the theoretical semi-menstrual inequality of the time of high and low water.

This inequality in the time of tides is, however, modified by the fact that the simultaneous occurrence of high water and Moon's transit, which for the Spring tide is assumed by theory, never and nowhere happens in reality. The tides in all cases occur later than the lunar transit that caused them, and the time elapsing between the two is called the "lunitidal interval." The above-found inequality in time will, therefore, in practice become apparent by the lengthening and shortening of the lunitidal interval for high water as well as for low water.

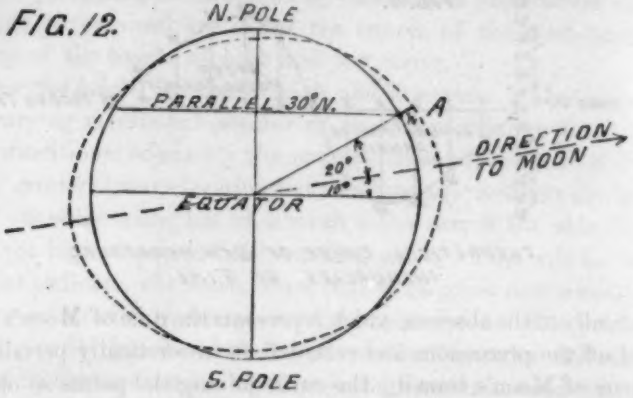
THE INFLUENCE EXERCISED BY THE DECLINATION OF THE MOON, OR THE DIURNAL INEQUALITY OF TIDE.

It is clear that the above-discussed variations in the Moon's declination must cause corresponding changes in her zenith distance from any given point, and thus influence the height of tide which, as we have seen, is dependent on the zenith distance of the attracting body.

To further illustrate this, let *A*, Figs. 12 and 13, represent a point somewhere on latitude 30° north, where an observer is stationed, the full drawn circle in both cases being a section through the Polar axis. Fig. 12 represents the situation when he observes a tide incident on the upper lunar transit, while Fig. 13 represents the situation

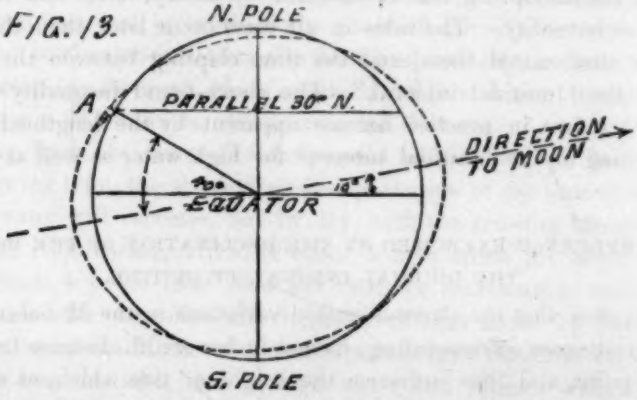
about 12½ hours later, when through the Earth's rotation the point *A* has passed to the other side (the Moon in the mean time, not having materially changed her position), and a tide incident on the lower

FIG. 12.



transit is observed. Now, if the Moon's declination is 10° north, then in the case of the upper transit her zenith distance, or the distance of the apex of the lunar wave from the observer is 30°—10°=20° while in the case of the lower transit it is 30°+10°=40°; in the first case,

FIG. 13.



the height of tide *h* must, therefore, be a higher one than in the second case, as shown in the diagrams. We consequently see that on our (northern) hemisphere during northern declinations of the Moon, a higher lunar contribution towards the tide is rendered by upper transits than by lower transits of the Moon, and it is equally clear that precisely the reverse must be the case during southern declinations of the

Moon; that is, that then the lower transits will render a higher contribution than the upper ones. We may, therefore, with reference to lunar declination, divide all high waters into two groups as follows:

1st Group.—High waters incident on:

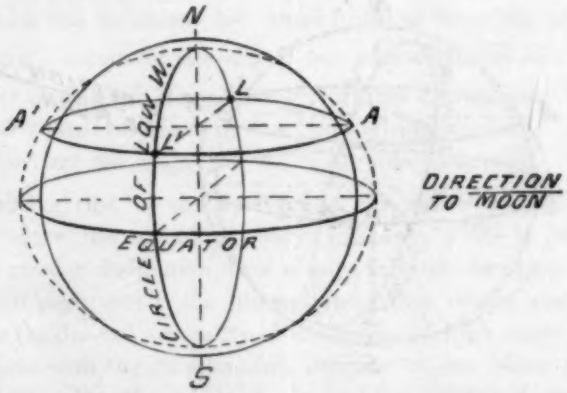
Upper transit of Moon during Southern declination;
Lower transit of Moon during Northern declination;
which are the *lower* high waters, and

2d Group.—High waters incident on:

Upper transit of Moon during Northern declination;
Lower transit of Moon during Southern declination;
which are the *higher* high waters.

Two tides (or high waters) following each other cannot, ordinarily, belong to the same group; the above established law will, therefore, find its expression in the difference in height, between the two high waters of the same day, and hence such difference is termed the diurnal or daily inequality in the height of tide.

FIG. 14.



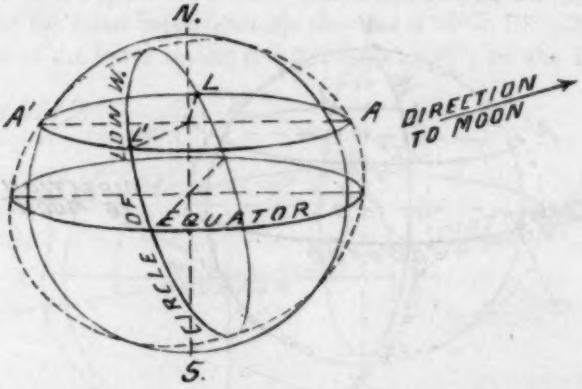
A simple reflection will show that, in the tides of the first group, the *greater* declination always produces the *lower* tide, while in the tides of the second group, the *greater* declination always produces the *higher* tide. The diurnal inequality consequently increases and decreases with the increase and decrease of the Moon's declination, and it would be reduced to zero, if the Moon was to stand in the Equator, during two high waters following each other. This, of course, can never be; yet, when the Moon is in the immediate vicinity of the Equator, it gener-

ally happens that two tides following each other belong to the same group, because the Moon, during the time that she passes from her upper to her lower transit, or *vice versa*, also passes the Equator, thereby changing her declination from North to South, or *vice versa*. In these cases therefore the small diurnal inequality that is at all possible, when the Moon stands near the Equator, may be annulled entirely.

Another important influence is exercised by the Moon's declinations on the duration of rise and fall.

When the Moon stands in the Equator, Fig. 14, then the circle of low water passes through the polar axis, dividing the two equal spaces from A to A', and from A' to A, into two equal spaces each. The time it takes the observer to pass from the high water at A, to the low water L, thence to the high water A', thence to the low water L', and thence to the high water A, is therefore the same in all cases, that is to say, rise as well as fall consume the same amount of time each, viz., about 6 hours 24½ minutes in all cases.

FIG. 15.



But when, as in Fig. 14, the Moon declines northerly, then the circle of low water is tilted into a slanting position to the polar axis, and the duration of the fall $A\ L$, and the rise $L'\ A$ becomes longer, while the duration of the rise $L\ A'$, and of the fall $A'\ L'$ becomes shorter. It will be noticed that the difference is due only to a shifting in the point or time of low water, the two high waters retaining their former position and distance from each other. Referring the time of low water to that Moon's transit which has caused the preceding high water, we can, therefore, exhaustively express this difference by saying that through the

Moon's declination the low water at L is *belated*, while through the same agency the low water at L' is made to come *earlier*. Or, calling the space of time between the low water and the lunar transit which caused the preceding high water, "the low water lunitidal interval," we may say, generally, that when the Moon declines northerly the lunitidal interval of the low water incident on the upper transit will be lengthened, and the lunitidal interval of the low water incident on the lower transit will be shortened through the Moon's declination. It will be understood, without further explanation, that the exact reverse takes place for southern declinations of the Moon.

This difference in the length of lunitidal intervals of every two low waters following each other, is called the diurnal inequality of the time of low water, and, according to the above, we can classify in reference to it in a similar way, as has been done before, in reference to the inequality of height, viz.:

1st Group.—Lunitidal intervals of low waters incident on:

Upper transits of Moon during Southern declination;
Lower transits of moon during Northern declination;
which are the *shorter* low water lunitidal intervals, and

2d Group.—Lunitidal intervals of low waters incident on:

Upper transits of Moon during Northern declination;
Lower transit of Moon during Southern declination;
which are the *longer* low water lunitidal intervals.

We perceive that in the first group the *greater* declinations must always produce the *shorter* lunitidal intervals, while in the second group the greater declination must always produce the *longer* lunitidal intervals. Consequently the diurnal inequality of the time of low water, like the diurnal inequality of the height of high water, increases and decreases with the increase and decrease of the Moon's declinations, and when the Moon is in the immediate vicinity of the equator vanishes entirely.

The declination of the heavenly bodies also causes a diurnal inequality in the time of high water. If, for instance, the Moon declines northerly and the Sun southerly, the Moon culminating, say, in the second hour, then during her upper transit the 2d group (higher) lunar wave combines with the 1st group (lower) solar wave, while twelve hours later, during the Moon's lower transit, the 1st group (lower) lunar wave combines with the 2d group (higher) solar wave; it is clear

that a difference in the time of the two high waters following each other must be the result of this.

It should be understood that the above discussion of the diurnal inequality treats of the *Northern* hemisphere only; for the *Southern* hemisphere group No. 1 would take the place of group No. 2, and *vice versa*. At the equator no diurnal inequality, neither of the height of high water nor the time of low water, exists.

THE INFLUENCE EXERCISED ON TIDES BY THE CHANGES IN DISTANCE OF SUN AND MOON FROM OUR GLOBE.

It is, *a priori*, evident that the changes in distance of the heavenly bodies must cause corresponding changes in the height of the component waves raised by them. The nearer either heavenly body is to us the higher will be the component wave raised by it and *vice versa*. At the same time the proportion between the two waves, which in the mean we have found to be as 2·214 : 1, is likely to be affected, and in order to find to which degree this may be the case, we will divide the general expression found for T_1^m by the one found for T_1^s (page 000), this division renders:

$$\frac{T_1^m}{T_1^s} = \frac{d^2 - (d - R\cos.\,a)^2}{(d - R\cos.\,a)^2} \cdot \frac{(D - R\cos.\,a)^2}{D^2 - (D - R\cos.\,a)^2} \frac{M^c}{S^c}$$

$$= \frac{(2d\,R - R^2\cos.\,a)\,(D - R\cos.\,a)^2}{(d - R\cos.\,a)^2\,(2D\,R - R^2\cos.\,a)} \frac{M^c}{S^c}$$

In this equation a may have had value between 0° and 90°; by putting $a = 90°$ we will at once simplify the calculation and obtain a result, which is a mean between the upper and the lower transit waves. For $a = 90°$ we obtain

$$\frac{T^m}{T^s} = \frac{2d\,D^2\,R}{2D\,d^2\,R} \frac{M^c}{S^c} = \frac{D}{d} \frac{M^c}{S^c}$$

Introducing now the value of the proportion $\frac{M^c}{S^c}$ as obtained before according to the Newtonian law, we have

$$\frac{T^m}{T^s} = \frac{D}{d} \frac{\frac{0{\cdot}0125}{d^2}}{\frac{319500}{D^2}} = \frac{D^3\,0{\cdot}0125}{d^3\,319500}$$

We perceive, therefore, that the proportion of the lunar to the solar wave, varies indirectly as the third power of the distance of the heavenly bodies varies. Now the difference between the greatest and least distance on the one side and the mean distance on the other side for the Sun amounts to about $\frac{1}{60}$ of the latter and for the Moon to about $\frac{1}{17}$. Supposing now the Moon to be in her greatest vicinity to the Earth, and the Sun to be at his greatest distance, then the above equations will render this result:

$$\frac{T^m}{T^s} = \frac{\left\{11567 + \frac{11567}{60}\right\}^3}{\left\{30{\cdot}13 - \frac{30{\cdot}13}{17}\right\}^3} \frac{0{\cdot}0125}{319500} = 2{\cdot}783$$

And again supposing the Moon to be at her greatest distance from the Earth, while the Sun is in his greatest vicinity, then the above equations will render this result:

$$\frac{T^m}{T^s} = \frac{\left\{11567 - \frac{11567}{60}\right\}^3}{\left\{30{\cdot}13 + \frac{30{\cdot}13}{17}\right\}^3} \frac{0{\cdot}0125}{319500} = 1{\cdot}773$$

We therefore perceive that the proportions of the lunar wave to the solar wave, which for the mean distance of both bodies we had found already to be 2·214, is a quantity varying between the two extreme limits of 2·783 and 1·773.

For the mean distance of both heavenly bodies the proportion between spring and neap tide can be expressed thus:

$$\frac{\text{Spring tide}}{\text{Neap tide}} = \frac{2{\cdot}214 + 1{\cdot}000}{2{\cdot}214 - 1{\cdot}000} = \frac{3{\cdot}214}{1{\cdot}214} = 2{\cdot}648$$

The two extreme cases, however, will be

$$\frac{\text{Spring tide}}{\text{Neap tide}} = \frac{2{\cdot}783 + 1{\cdot}000}{2{\cdot}783 - 1{\cdot}000} = \frac{3{\cdot}783}{1{\cdot}783} = 2{\cdot}122$$ { Moon at least and Sun at greatest distance.

$$\frac{\text{Spring tide}}{\text{Neap tide}} = \frac{1{\cdot}773 + 1{\cdot}000}{1{\cdot}773 - 1{\cdot}000} = \frac{2{\cdot}773}{0{\cdot}773} = 3{\cdot}587$$ { Moon at greatest and Sun at least distance.

Besides the above-mentioned influences, the variations in the distance of the heavenly bodies also exercise an influence on the time of high and low water, because the lunitidal intervals of high and low water must be the shorter the nearer the heavenly bodies are to us, as

the higher wave raised by them then, will move swifter than a lower one, raised when they are further off.

The semi-menstrual inequality, the diurnal inequality and the inequalities caused by the variations in the distance of Sun and Moon, each of them represent a series of regular changes occurring within a short period of time, the duration of which is a different one in each case and the various phases of which are, therefore, constantly shifting their position towards each other. Besides this, the limits of lunar parallax and declination are not constant, but, as we have seen vary, in periods of $9\frac{1}{2}$ to 19 years respectively; this latter period of time then would be the one at the expiration of which the heavenly tide-generating conditions would repeat themselves in the same combinations, if it were not for additional complications being introduced through variations in the limits of solar declination and distance. These being of no practical importance, however, will not be discussed here, beyond stating, that strictly speaking, many thousand years must elapse before the heavenly tide-generating conditions can repeat themselves in precisely the same combinations.

The sidereal causes affecting tides, can as we have seen, be brought into a theoretical system based upon exact science. If there were no other interfering influences, and if all the suppositions on which we have founded our theory were correct, then tides would occur conforming to the same, and the time and height of any high or low water, at any given place on Earth, could be predicted with absolute certainty.

But, in the first place, our suppositions are not correct. We have assumed the Earth to be surrounded uniformly by water, which as we know is not the case. The oceans are bounded everywhere by continents, and even the largest of them, the Pacific Ocean does nowhere extend over more than 90 degrees of longitude, while the tidal wave of theory extends over 180 degrees. Consequently, even our largest ocean is far from offering the conditions of size required for the formation of a tidal wave, according to theory.

Again, we have assumed "that in the water there are no molecular forces resisting the actions of the tide-generating forces," that is that the particles of water are devoid of cohesion. This assumption, although approximately correct, is known not to be strictly so and is made only in default of accurate knowledge on the subject. As long as an intimate knowledge of this property of water and of the laws

governing the motion of its particles is not obtained our theoretical results regarding the raising and propagating of tidal waves necessarily are only approximately correct.

Nor is this all; a number of other terrestrial causes combine to continually influence and modify the generation of the tidal waves. In deep water the wave will move swifter and rise higher than in shallow water. In long and narrow bays we frequently find astonishing heights of tide, while at a projecting point of the coast line, perhaps close by the rise is insignificant. The influence exercised by the topographical formation of coast lines is strikingly described by Lentz, ("*Ebbe und Fluth des Meeres*," Hamburg, 1873), in the following words:

"The intricate theoretical tide-generating conditions are complicated still more by a number of other circumstances, thus forming a bewildering labyrinth of causes and results, through which the human mind cannot find its way. The tidal waves meeting islands in their course are parted by them, and a wave reaching a certain point by one road will there meet another one that has arrived at the same point by another road. Both will penetrate each other, will locally annul and locally augment each other, according to the way they meet and a wave thus combined will take a new course with an altered height and velocity until it meets a third wave with which it will form new combinations, and thus an endless series of varying phenomena, impenetrable to the human eye, will be created.

"The numberless tidal waves rushing through the oceans in all directions, we cannot better picture to ourselves than by throwing ten or twenty stones into a small pond and then watching the various systems of waves that in the course of a few moments have formed on the surface and are now traveling in all directions, crossing, penetrating, annulling and augmenting each other. If we were to observe at a few given points on the banks of this pond the forms of waves appearing there, then from such local observations we would learn about as much of the various systems moving on the surface of the pond, as we now know about the tidal waves moving on our oceans."

Lentz adds: "This certainly is discouraging, we only know that we do not know anything," and so far as our knowledge of the phenomena in open ocean is concerned he certainly is right. We can only gain an insight into the phenomena as they appear on our shores, where actual observations can be made, and although the results of

these will nowhere be found to exactly correspond to theory and will even frequently depart very far from it, yet the laws of the latter can always be recognized in long series of local observations, modified in each case by those local constants that are produced through terrestrial influences at the particular point of observations.

Besides the local causes influencing tides, which emanate from the topographical and hydrographical features of the locality and its surroundings, and which, therefore, are of a permanent character, there are a number of other terrestrial influences of a varying and fluctuating description, such as wind, temperature, barometrical pressure, atmospherical precipitations, etc. Although in the means of a sufficiently long series of observations these influences will have a constant value, yet to the individual case they impart a vacillating character, which cannot be framed into any law, and thus they form the source of unavoidable discrepancy between prediction and actual observation.

Assuming, ~~as above~~, that a period of nineteen years contains practically all the possible combinations of the heavenly tide-generating conditions, then the means of all the tides at a certain place during such period may be looked upon as the *mean tidal establishment* of the locality, the principal items of which are as follows:

MEAN TIDAL ESTABLISHMENT.

1. The corrected establishment, or high water mean lunitidal interval.
2. The low water mean lunitidal interval.
3. The mean height of high water.
4. The mean height of low water.

From these, by means of simple operations, the duration as well as the range of tides can be found.

These mean values, as deduced from a series of nineteen years, correspond to certain mean values of the heavenly tide-generating conditions, and, in order to test to what extent the means of a shorter period (supposing a full one is not available), deviate from the values of the true mean establishment, we have to compare the means of the heavenly conditions in the latter case with those of the first case. If they are equal in both cases, then we are justified in presuming that our shorter series has rendered the values of the true mean establishment. If they are not equal then corrections must be applied as will be shown subsequently.

The mean establishment once found, then in order to compute or predict the *time* of high or low water for any individual case, we simply add to the mean lunitidal interval of high water and respectively low water, the corrections for the hour of moon's transit, for declination and for parallax of the heavenly bodies.

In order to find the *height* of high or low water we have to construct from the known resultant wave the two component waves. Having done this the height for high as well as low water, for any given individual case, is determined by the equation.

$$\text{Height} = M_\alpha + S_\beta$$

wherein

α = Zenith distance of Moon from the place of high and respectively low water, at the time of the generating lunar transit.

M^α = Lunar elevation or depression pertaining to such zenith distance.

β = Zenith distance of Sun from the place of high and respectively low water, at the time of the generating lunar transit.

S^β = Solar elevation or depression pertaining to such zenith distance.

The values M^α and S^β will be influenced by the varying distances of the heavenly bodies and have to be corrected according to the determined magnitude of such influence.

The deduction, from actual observations made at a certain point, of the local laws governing tides there, and of a system for predicting them, resolves itself as we see into:

1. The determination of the local mean tidal establishment.

2. The determination of the influence of lunar and solar declination and parallax on time and height of high and low water.

3. The resolution of the resultant tidal wave into its two component waves.

The way in which the first problem is approached has been indicated already.

The general method of solving the second problem will be to group the available observations in such a way, that two groups will render means in which the sidereal conditions are alike with the exception of one of them. Then the inference is justified, that the differences found in the means of the observations (be it time or be it height) are due to the difference in that only one of the sidereal conditions, the mean of which is unequal in the two groups, and this inference will be all the

safer, the greater the number of observations is which compose each group.

The third problem is solved in the same way, the unequal means of sidereal conditions here always being the zenith distance of either Sun or Moon. The resulting differences of height then must be the differences of height between the various concentric circles of either the lunar or the solar wave (Fig. 7) and by means of a sufficient number of such differences the contours of the component waves can easily be determined.

The introduction of the zenith distance, in the equations for height, is advantageous, in so far as in the place of two unknown quantities—the influence of declinations and of hour of Moon's transit—we only have to deal with one—the influence of the zenith distance. It necessitates the construction of tables from which the zenith distance of Moon and Sun from the place, respectively, of high and low water, at the time of the generating lunar transit, can be found, pertaining to each hour of Moon's transit and each degree of declination on either side of the Equator. These tables as constructed for Cape Henlopen, Delaware Bay, will be given in the second part of this paper; they are applicable for any place in the vicinity of latitude 40° N, the corrected establishment of which does not materially deviate from that of Cape Henlopen.

INFRA-RED EMISSION SPECTRA.—By the use of a new form of spectroscope and of a suitable phosphorescent material, which has been previously rendered luminous, Henri Becquerel has been able to subject the lines and active bands in the lower portions of emission spectra to microscopic examination and to determine the wave lengths of the most brilliant lines in some of the incandescent metallic vapors, such as potassium, sodium and cadmium, by projecting the diffracting spectra furnished by one of Rutherford's very beautiful metallic rulings. The results show a remarkable richness in the infra-red region, which comprises an interval of wave-lengths more extensive than the aggregate of the visible region and of the ultra-violet region. The investigation seems likely to furnish valuable information concerning still unknown laws which regulate the vibratory movements of incandescent vapors.—*Comptes Rendus*, Aug. 25, 1884. C.

STAR PHOTOGRAPHY.—The application of photography to the construction of star charts, which was introduced many years ago by Rutherford & Gould, has lately been undertaken at the Paris Observatory, by the Messieurs Henry. Admiral Mouchez, in a communication to the French Academy, describes the apparatus which they employ, and states that by its aid a chart can be prepared in a single hour, which would require, by the ordinary methods, many months of assiduous labor.—*Comptes Rendus*, Aug. 18, 1884. C.

GLIMPSES OF THE INTERNATIONAL ELECTRICAL EXHIBITION.

By Professor Edwin J. Houston.

No. 6.—McDonough's Telephonic Inventions.

The pioneer work done by Reiss in the development of the articulating telephone, quite naturally attracted the attention of numerous investigators and inventors in different parts of the world, and resulted in the production of various forms of apparatus intended for the electrical transmission of speech. Among the earlier investigators in this field the name of James W. McDonough occupies a prominent place.

McDonough came prominently before the scientific men in this country as a party to the famous telephone interference suits, declared in the United States Patent Office during the last eight or nine years. On the 10th of April, 1876, McDonough filed an application in the United States Patent Office for a "Teleloge, or a means for transmitting articulate sounds from one place to another through the medium of electricity." This application was placed in interference with the patent of Bell, dated March 7, 1876, and afterwards with the following applications; viz., that of Edison, of December 24, 1877; Dolbear, October 31, 1877; Richmond, August 24, 1877; Gray, October 29, 1877, and Holcombe, January 28, 1878.

The applications of the above parties, together with those of Berliner, Voelker, Blake and Irwin were placed in interference with Bell and with one another, and formed a long series of interference suits that have not yet been finally decided.

McDonough was admitted to the above interferences on the subject-matter of his receiver only. For reasons we shall afterwards refer to, he was excluded by the Office from participation in the other interference suits. The case in which he was a party was known in the Office as case G.

The subject-matter of this case was "Held to embrace a receiver containing an electro-magnet and a diaphragm supported and arranged in close proximity thereto, and adapted to respond to variations in the electric current passing through the coils of the magnet when used in connection or combination with a transmitter adapted to create sound-producing fluctuations in the electric current, whether said electrical

variations, waves, pulsations, or undulations represent, or are derived from, sound-waves, or mechanical vibrations."

The above interference involved the extremely important issue as to the true inventor of the telephone receiver. After a long and thorough examination of the case it was decided by the Examiner in Interference cases by the awarding of priority of invention to McDonough. On appeal, however, to the Examiners-in-Chief, this decision was reversed and priority of invention awarded to Bell. The case is now on final appeal to the Commissioner of Patents, and awaits his decision.

Although the application of McDonough was made on the 10th of April, 1876, or after the issue of Bell's patent, of March 7, 1876, yet it was made before the date of Bell's lecture, May 10, 1876, or before the actual introduction or use of his articulating telephone. "So that," says the Examiner of Interferences, "McDonough's efforts in this direction may be regarded as entirely independent of and uninfluenced by Bell's disclosures and inventions."

Before describing McDonough's application of 1876, we will give a brief account of his experiments and inventions leading thereto.

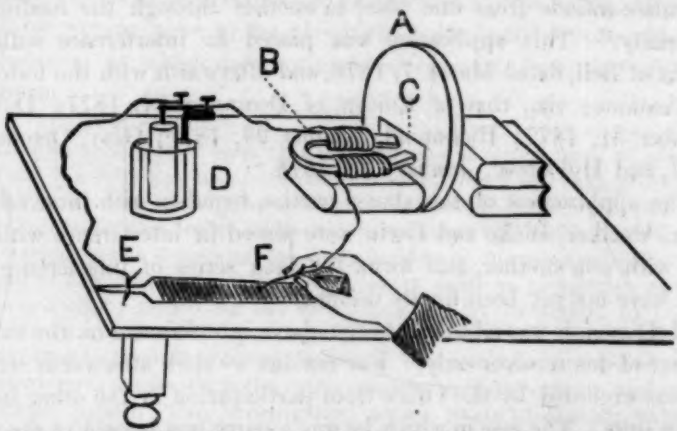


FIG. 1.—Apparatus of 1867, for obtaining Sounds by Interrupted Currents.

According to a sworn deposition made by McDonough in a telephone suit, his first experiments bearing on the subject of telephony were made in 1867, when he constructed an apparatus by means of which he was enabled to obtain a continuous sound by means of an interrupted current of electricity. This apparatus, which is shown in Fig. 1, consisted of a horseshoe electro-magnet *B*, placed before a paper

diaphragm *A*, tightly stretched over an iron hoop. On the paper diaphragm, facing the poles of the horseshoe magnet, was attached a small piece of tinned iron *C*. The diaphragm and magnet were suitably supported on books and placed in the relative positions shown in the figure.

One terminal of a battery cell was connected with one of the terminals of the magnet coil, and the other terminal *E*, of the battery was wrapped around the end of an ordinary file *F*. When, now, the free terminal of the horseshoe magnet was drawn over the surface of the file, the makes and breaks thus effected in the battery current, produced fluctuations in the magnetism that corresponded with the fluctuations thrown on the electric current traversing the magnet coils, and thus produced movements in the diaphragm. A movement of contact, effected when the terminal touched the file, permitted the current to flow, and thus resulted in the attraction of the tinned iron to the magnet. A movement of the contact away from the file, causing a break in the circuit, permitted the diaphragm to move from the magnet in consequence of its elasticity.

With this early apparatus, McDonough was able to produce sounds that were audible at a distance of several feet from the diaphragm. The pitch of the sounds produced, of course varied with the rapidity of motion of the wire over the file.

Unfortunately McDonough does not appear to have preserved this early form of apparatus. All of it that remained in his possession in 1876, was the magnet, and the iron ring on which the paper diaphragm was stretched. Nor does he appear to have shown this experiment to others. At least he brings no witnesses to testify to having seen the parts assembled in the relations shown in Fig. 1.

Assuming, as we may fairly do, when taken in connection with subsequent apparatus that was shown to competent witnesses, that McDonough actually produced the combination of parts shown in Fig. 1, at the date alleged; viz., in 1867, then *great* credit is due him for the decided invention thus effected, since he has produced what may be fairly regarded as a new combination of parts whereby improved results can be obtained. For, when, at a later date, he placed such a magnetic diaphragm in combination with a telephone transmitter varied by the voice, he did much to place the articulating telephone in its present successful commercial position.

When we speak of the preceding combination of parts being novel when used to produce sounds by means of varied currents of electri-

city, we are not unmindful of the experiments of Page, in 1837, who obtained musical sounds from a magnet when an interrupted current was passed through a flat spiral placed between the poles. These early observations, which were confirmed by more extended experiments of De la Rive, and of Delezenne, were ascribed to molecular changes in the iron during its magnetization and demagnetization. In the McDonough experiment, the movements of the diaphragm producing the sound are not molecular, but mass vibrations. The entire diaphragm moves to or fro under the variations in the magnetic attraction. It is such a form of diaphragm that practice shows to be so valuable when used as a receiver for the articulating telephone.

McDonough does not appear to have done anything more with his apparatus than to have tried its capacity for producing sounds, more or less continuous, by the action of an intermittent current. Although he may have vaguely conceived the possibility of applying the apparatus to the transmission of articulate speech, yet such conceptions do not seem to have taken definite form until August 26, 1871, when he made the sketch that is represented in Fig. 2.

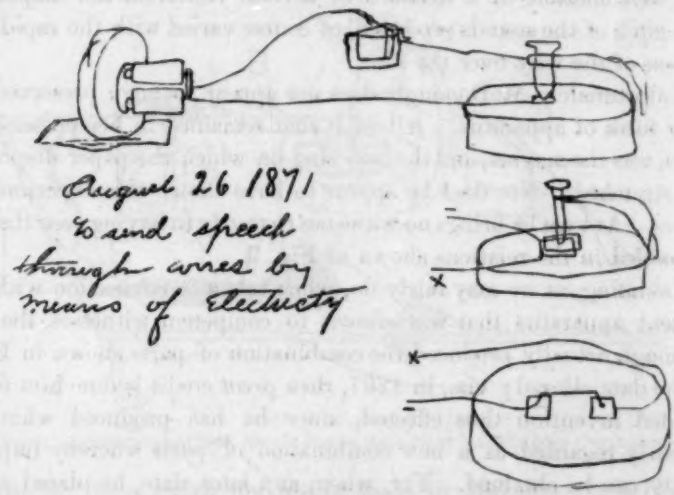


FIG. 2.—McDonough's Sketch of August 26, 1871.

This sketch, which was made in a memorandum book containing sketches and suggestions respecting some thirty different inventions, was the result of an idea conceived by McDonough after reading descriptions of the phonautograph, and of the Reiss telephone. The legend of

the sketch, "To send speech through wires by means of electricity," clearly indicates the purpose of the apparatus. No other description accompanies the drawing, and in interpreting it we must bring to bear on it such a knowledge of the state of the art only, that it is fair to suppose was possessed by McDonough at the time he made the sketch. As to the apparatus shown on the left hand, its purpose is obviously the same as that of the experiment of 1867. The apparatus shown in the middle of the upper drawing is clearly a battery, since it is stated that the combination of parts is to be operated through the agency of electricity. As to the various forms of apparatus shown on the right hand of the sketch, they are apparently diaphragm-transmitters of the Reiss type, designed to be used in the manner fully described by Reiss. Moreover, the apparatus shown in the lower, right hand sketch is substantially the form of transmitter figured in his application of April 10, 1876. Since McDonough was acquainted with the experiments of Reiss, and had experimented as to the ability of a magnetic diaphragm to be set into motion by means of a varied electrical current, it is fair to suppose, admitting the credibility of the sketch, that he intended to combine his magnetic diaphragm, with a voltaic battery and a modified Reiss transmitter.

McDonough does not appear to have actually embodied his invention in a working model until the latter part of May, 1875. This delay was owing to ill health, change of residence, and great press of other business. In May, 1875, however, he constructed his first telephonic apparatus.

The membranes of the transmitting and receiving instruments were stretched over the ends of two cylindrical tin cases. A piece of tinned iron was fastened on the diaphragm of the receiving instrument, and the poles of an electro-magnet were placed in proximity thereto. Near the centre of the diaphragm of the transmitting instrument was secured a small piece of tin foil. This diaphragm was suitably supported in a horizontal position. A needle, passing through a glass tube supported in a vertical position over the diaphragm, rested with with its lower end on the plate of tin foil. The needle was free to move up and down, and formed one of the terminals of a battery, the other terminal being connected with the line. This form of apparatus was somewhat modified in June, 1875, when the form given to it was as shown in Fig. 3.

In this form of apparatus the tin foil was replaced by a small plate of German silver. *A*, represents the tin-can receiver, with its diaphragm, *C*, and plate of tinned iron, *E*. The electro-magnet, *F*, is adjustable with reference to the diaphragm. The transmitter consists substantially of the tin can, *B*, on the diaphragm of which is placed the German silver plate, *H*. The glass tube, *J*, contains the contact needle. The connections with the battery, *G*, are as shown. With the preceding apparatus, familiar tunes were successfully transmitted, but no words.

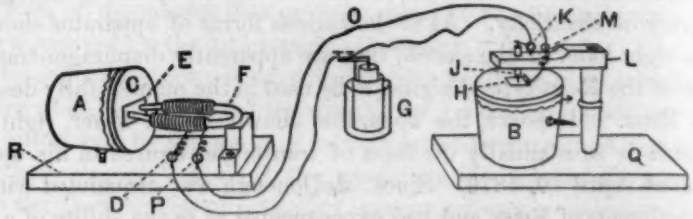


FIG. 3.—McDonough Telephonic Apparatus of June, 1875.

Fig. 4, shows the details of a modified form of apparatus constructed by McDonough later, in June, 1875. The membrane, *A*, is stretched over an iron hoop. *B*, is an iron plate, fastened to the diaphragm. The electro-magnet, *C*, is securely mounted, in the position shown, on an adjustable standard.

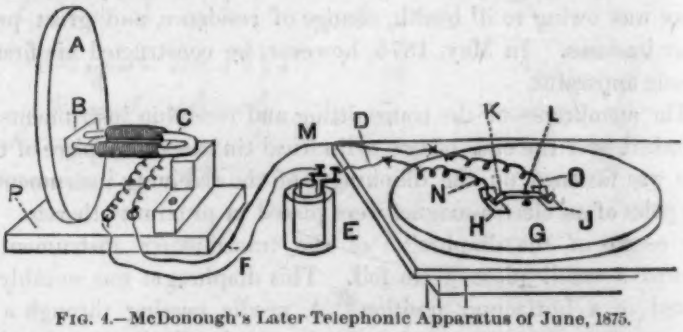


FIG. 4.—McDonough's Later Telephonic Apparatus of June, 1875.

The transmitter consists of a parchment diaphragm *G*, stretched over an iron hoop or ring. Two metal plates, *H*, and *J*, of German silver, are securely attached to the diaphragm, about an inch and a half apart and connected with the wires, *N*, and *O*, as shown. A light strip of metal, *K*, bent in the form shown, rested on the metallic plates, *H*, and *J*, and completed the electric circuit between them. The bolt,

L, with a nut for adjustment, was subsequently added in order to prevent the vibrations of the diaphragm from moving the metallic bridge, *K*, away from the metal plates, *H*, and *J*. One of the above mentioned iron hoops was the one employed in the experiment of 1867.

The above apparatus, which was completed about the middle of June, 1875, was successfully employed for the transmission of articulate speech on many occasions during the same month. A number of witnesses testify to having heard articulate speech by the use of the preceding instruments.

Only parts of the apparatus of June, 1875, were preserved. These were used as exhibits in the United States Patent Office interference case with Bell and the other parties mentioned. The instruments, however, were reproduced with all the exactness possible, and are represented in Fig. 5. This apparatus has been successfully used by several parties for the transmission and reproduction of articulate speech.

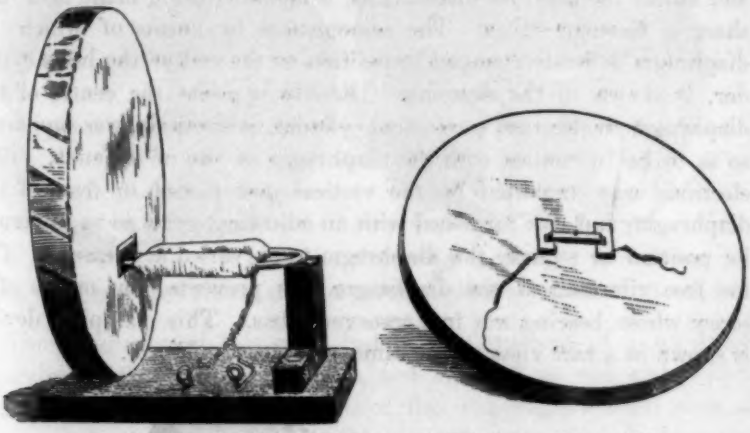


FIG. 5.—Reproductions of McDonough's Telephone of June, 1875.

Having satisfactorily shown the capability of his instruments to transmit articulate speech, McDonough set to work to improve the strength of the sounds reproduced by the receiver. Prior to the filing of his application for a patent on the 10th of April, 1876, he constructed and carried on numerous experiments with some fifteen different instruments, frequently interchanging the transmitters and the receivers.

We will describe a few of the more important of these early forms

of articulating telephones. Fig. 6, shows an instrument constructed and used by McDonough in September, 1875.

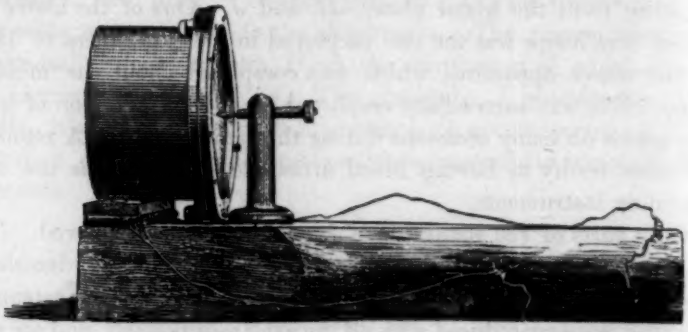


FIG. 6.—McDonough's Metallic-Diaphragm Transmitter, September, 1875. (Exterior.)

The diaphragm in this instrument is mounted on a brass cylinder, and unlike the previous diaphragms, is metallic, being made of a thin sheet of German silver. The arrangement by means of which the diaphragm is firmly clamped in position on the end of the brass cylinder, is shown in the drawing. Directly opposite the centre of the diaphragm an electrical conducting cylinder, or electrode, was supported so as to be in contact with the diaphragm at one of its ends. This electrode was supported by the vertical post placed in front of the diaphragm, and was furnished with an adjusting screw so as to permit its position as regards the diaphragm to be varied at pleasure. The too free vibration of the diaphragm was prevented by means of a screw whose bearing was in a transverse bar. This clamping device is shown in a rear view of the same apparatus in Fig. 7.

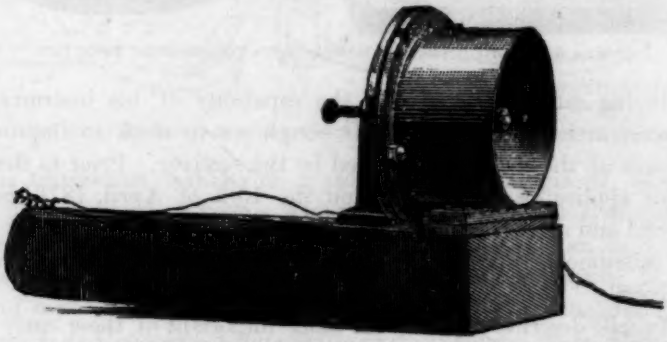


FIG. 7.—McDonough's Metallic-Diaphragm Transmitter, September, 1875. (Interior.)

One of the circuit wires was connected with the metallic diaphragm and the other with the contact electrode. Various materials were employed for the contact electrode, such, for example, as nickel, German silver, platinum, steel and carbon. The latter, which appeared to give the best results, was formed of the graphite of an ordinary lead pencil.

The transmitter of September, 1875, was used in connection with the receiver of June, 1875, as well as with other receivers.

A later form of transmitter and receiver were constructed by McDonough in October, 1875, and named by him "The tin-drum pendulum" instruments. These instruments are shown in Fig. 8.

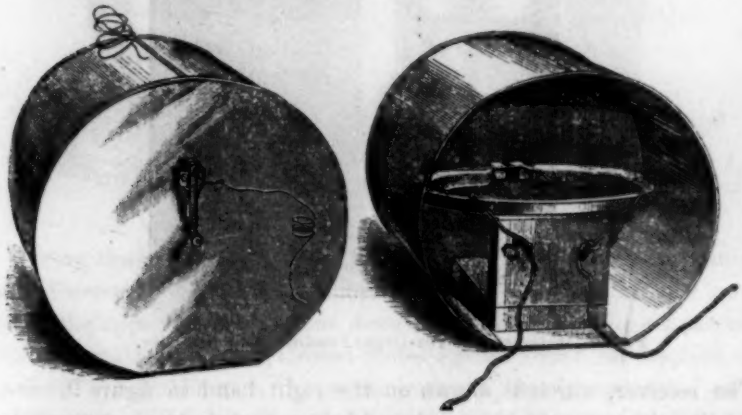


FIG. 8.—McDonough's Tin-Drum Pendulum Transmitter and Receiver, October, 1875.

The transmitter of this set of instruments consisted of a tin-drum or cylinder flattened on one side, and enclosed at one end, which formed a diaphragm; at the centre of this diaphragm a small piece of platinum was soldered and formed a contact point for an electrode, which, as before, was formed of various materials such as platinum, steel, brass or carbon. The electrode was "inserted in a socket formed in the end of an adjustable screw, which was carried by a hinged pendulous bar of brass, about two and one-half inches in length. The pendulous bar was so hinged as to press the electrode in towards the platinum." The details of this device will be the better understood from an inspection of Fig. 9, which shows another view of the transmitter. The hinged end of the pendulous brass bar was supported on any insulating material. One terminal of the line was

connected to the pendulous bar and hence to the contact electrode, and the other end to any part of the tin-drum, and therefore to the platinum plate.

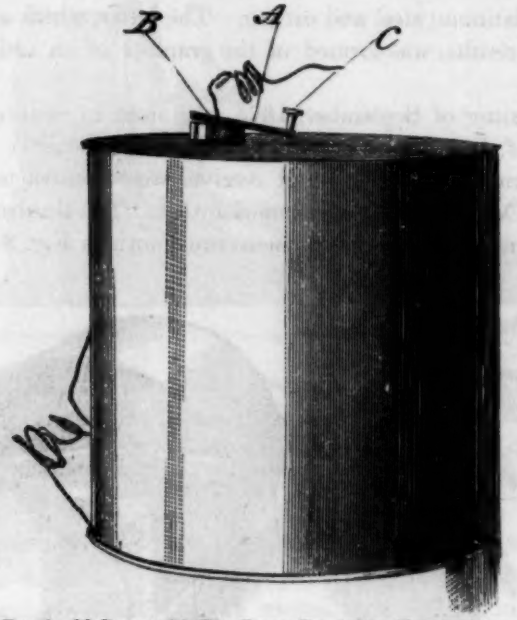


FIG. 9.—McDonough's Tin-Drum Pendulum Transmitter.

The receiver, which is shown on the right hand in figure 9, consisted like the transmitter, of a tinned-iron cylinder, closed at one end, and flattened on one side. Inside the cylinder, suitably supported on an upright stand, was placed an electro-magnet, with its poles in close proximity to the tinned-iron diaphragm.

The above instruments successfully transmitted and reproduced articulate speech, but, as might be supposed, the resonance of the apparatus somewhat interfered with the distinctness of the articulation.

A subsequent set of instruments known as "The Brass-Drum" instruments, are shown in Fig. 10.

A brass cylinder *A*, has a membrane tightly stretched over one of its ends by means of the tightening ring *B*, and the adjusting screws *C*, An adjusting screw and its socket-electrode are placed, as shown at the centre of the diaphragm. A wooden ring *G*, is provided for supporting the tightening ring and diaphragm. The instruments rest on the under base *H*. The hinged doors in the instruments are provided for

adjusting of an electro-magnet placed inside each drum, with its poles near a metal plate secured to the under side of the diaphragm. As in the previous instruments, various forms of electrodes were employed in connection with the adjusting screw. Since each of these instruments was provided with an electro-magnet, either could be employed alternately as transmitter and receiver.

FIG. 10.—McDonough's Brass-Drum Telephone.

Having thus briefly traced the progress of the invention as claimed by McDonough, and testified to by competent witnesses, we will now discuss the apparatus which was described and figured in connection with his application in the United States Patent Office, on the 10th of April 1876, together with the working model that accompanied said specification. The drawings that accompanied this specification are shown in Fig. 11.

"In Fig. 1," is shown a perspective view of the "teleloge."

"Fig. 2," represents a section taken on the line *xx*.

"Fig. 3," represents a vertical transverse section taken on the line *yy*.

"Fig. 4," is a general top view of the same.

Quoting the language of the specification: "The object of my invention is to provide a means for transmitting articulate sounds from one place to another, through the medium of electricity, and it consists in the combination with an electrical battery, circuit wires, armature, magnet, and circuit breaker, of a transmitting and a receiving membrane or sounding apparatus, so constructed as to vibrate in accord with the vibrations of articulate sound, and so arranged relative to the magnet and circuit-breaker that the vibrations of the transmitting membrane or apparatus, produced by articulate sounds, are transmitted by the

electrical current to the receiving membrane or apparatus, and so as to cause a like vibration of the receiving membrane or apparatus, and to cause it to reproduce the articulate sounds transmitted from and by the transmitting membrane or apparatus. My invention also consists in the novel construction of the circuit breaker, as is hereinafter more fully described."

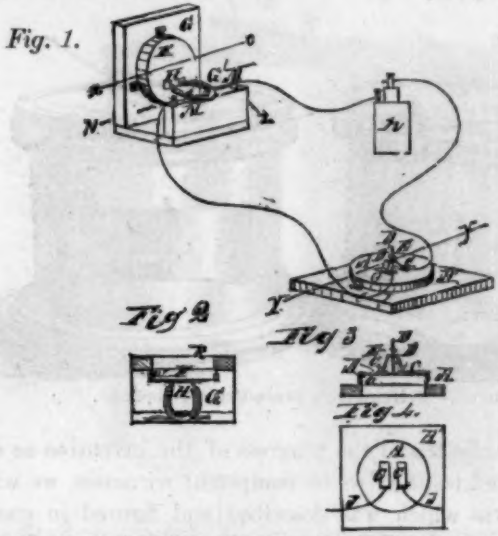


FIG. 11.—McDonough's Drawings accompanying specification of Letters-Patent for a "Teleloge," filed April 10th, 1876.

Then follows a description of the drawing. The transmitting membrane or diaphragm, shown at *A*, is composed of vellum or other suitable material so stretched over a metal hoop, or ring *a*, as to be capable of being tightened or loosened as desired. *C*, *C*, are two metal plates attached to the upper surface of the diaphragm, near its centre, in the relative positions shown, and are suitably insulated from each other. The metal bolt *D*, permanently attached at its lower end to the centre of the diaphragm, between the two plates, and insulated from them, passes through an opening in the middle of the arch-shaped circuit-breaker *D'*, and is furnished with an adjusting nut *F*, that serves the purpose of limiting the movements of the circuit-breaker *D'*. The circuit-breaker *D'*, consists af an arch-shaped piece of metal loosely secured at its centre on the bolt *D*, and having its extremities bent upward at each end so as to provide contact surfaces that rest on the metal plates *C*, *C*.

The receiving instrument consists of a diaphragm of vellum or other suitable material "sensitive to the vibrations of sound," stretched on a metal hoop or band a^1, in the position shown. An electro-magnet G^1, is placed with its poles opposite an armature H, attached to the surface of the diaphragm.

The circuit connections are as follows; viz., one wire from the battery h, is connected with one of the metal plates C, and the other with one end of the coil of the electro-magnet of the receiving instrument. The other plate C, is connected with the remaining terminal of the electro-magnet G'.

The operation of the apparatus as described by the inventor is as follows, viz.: "The transmitting membrane A, being sensitive to the vibrations of articulate sounds produced thereon, is caused to vibrate in sympathy therewith, thereby imparting an upward movement to the circuit-breaker at each vibration, disconnecting it from the plates C, C, and alternately breaking and closing the circuit, when the intermittent current alternately magnetizes the magnet G', attracting the armature H, and causes it, and the membrane F, to vibrate simultaneously with the vibrations of the transmitting membrane A, and in accord therewith, and so that the membrane F, reproduces the articulate sounds transmitted from and by the membrane A."

The working models accompanying this specification were destroyed in the fire at the Patent Office. A duplicate set of instruments was subsequently made and deposited in the Patent Office in lieu of those destroyed. Another set of duplicates was also made for examination and trial by experts. The details of these models are shown in Fig. 11.

We have already called attention to the fact that the above application was put in interference with Bell and the other applicants in the matter of the receiver only. This circumstance was due to the fact that the U. S. Patent Office held to the belief in the "undulatory current theory" as being essential to the transmission of articulate speech. It argued that speech could not be transmitted by make and break currents, and that since McDonough's apparatus decribe l such currents it could not be considered as an articulating telephone transmitter. This singular process of reasoning, which was perhaps only the natural result of an unhesitating acceptance of a theory which can by no means be regarded as unquestionably proved, was maintained despite the fact that the model deposited in the office with the specification and drawings, together with the other apparatus we have described,

could and did transmit intelligible, articulate speech, as has been amply testified by experts of unquestionable integrity and ability. No question, however, appears to have been raised as to the ability of the receiving instrument to reproduce sounds of all kinds, including intelligible, articulate speech, so that the Examiner of Interference awarded the priority of invention on this count of the interference to McDonough, above all the other contestants.

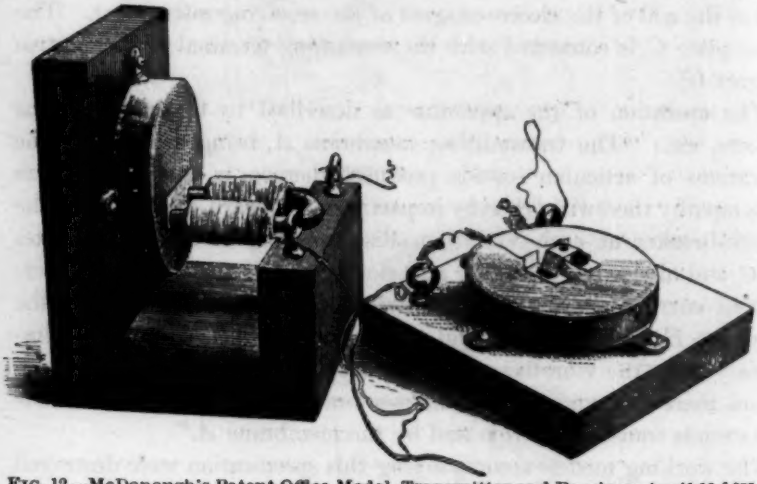


FIG. 12.—McDonough's Patent Office Model, Transmitter and Receiver, April 10, 1875.

The subject-matter of the interference in case *G*, on Gray's claim, application of October 29, 1877, is as follows, viz.: "A telephonic receiver consisting of the combination in an electric circuit of a magnet and a diaphragm supported and arranged in close proximity thereto, whereby sounds thrown upon the line may be reproduced accurately as to pitch and quality."

In the printed record containing the decision of the Examiner of Interferences it is acknowledged that a diversity of opinion exists as to the scope of this claim, and the interference founded thereon. It is claimed, on the one side, the designation, "A Telephonic Receiver," together with its prescribed capacity, "whereby sounds thrown upon the line may be reproduced accurately as to pitch and quality," is tantamount to a claim for the combination of such receiver with an instrument capable of producing electrical waves or undulations bearing the impress of sound waves."

"On the other hand, it is maintained that the claim is to a described

combination of these elements; an electric circuit, a magnet, and a diaphragm; the parts being so disposed and arranged as to manifest, among other functions, the capacity to reproduce sonorous vibrations electrically transmitted, and that the particular means for creating the electric current which is to be translated into sound-vibrations form no limitation upon the invention."

The Examiner-in-Interferences adopted the view that the issue embraced the telephone receiver alone, and on this construction of the issue awarded the priority of invention to McDonough. The Examiners-in-Chief, however, to whom, as we have already remarked the case was appealed, adopted the view that the issue clearly necessitated the combination with the receiver of a transmitter capable of throwing on the line the peculiarities of articulate speech. On the assumption that a transmitter constructed as was that of McDonough's could not transmit articulate speech, and that therefore the combination of such a transmitter with a diaphragm receiver was not effected, the Examiners-in-Chief, awarded the priority of invention to Bell. The above, as we have already remarked, was the natural conclusion, in view of the belief of the Examiners-in-Chief, as to the necessity for an undulatory current for the transmission of articulate speech.

There appears to be ample testimony by the most able experts that apparatus constructed in accordance with the McDonough specification of April 10, 1876, can and does clearly transmit intelligible articulate speech. McDonough's apparatus combines with a magnetic diaphragm receiver, what may, perhaps, be regarded as a variety of Reiss transmitter. If then it be admitted that the Reiss transmitter had never previously transmitted intelligible articulate speech, which we deny, then since it does transmit it when coupled with a magnetic diaphragm receiver, it might appear that the essence of the invention of the articulating telephone consisted in the invention of a suitable receiver to be used in combination with a Reiss transmitter.

No little probability would appear to be given to this view, from the generally acknowledged fact that the Reiss transmitters operate very satisfactorily when combined with magnetic diaphragm receivers.

It is, indeed, in our opinion, an open question whether the real improvement in the art that placed the telephone as left by Reiss in the extensive commercial use it now has, did not in reality consist rather in the invention of a more suitable receiver than it did in any modification the Reiss transmitter has since received. We can readily

understand how a current, modified by the action of the human voice on a Reiss transmitter, would produce in a magnetic diaphragm such undulations in its magnetic field as would result in the movements necessary to reproduce the articulate speech thrown on the transmitter.

Such a view, it will be seen, takes the assumed necessity for the undulatory character, in the somewhat narrow sense in which it is generally construed, from the electric current transmitted, and places it in the transmitting and receiving diaphragms, so that the movements of the receiving diaphragm would still be an exact reproduction of those of the transmitting diaphragm.

When describing the inventions of Reiss, we will discuss at greater length the peculiarities of the electrical currents transmitted in telephony.

CENTRAL HIGH SCHOOL,
PHILADELPHIA, February 14, 1885.

PHYSICAL CONSTITUTION OF THE SUN.*

BY PROF. CHARLES A. YOUNG.

The lecturer was introduced by Dr. WILLIAM H. WAHL, Secretary of the Franklin Institute, who said:

LADIES AND GENTLEMEN:—Professor Charles A. Young, Past President of the American Association for the Advancement of Science, will lecture to you this evening on the "Physical Constitution of the Sun." It is hardly necessary for me to remark that there is no physicist in this country more competent to discuss this subject than Professor Young, whom it affords me great pleasure to introduce to you.

PROFESSOR YOUNG:—Ladies and gentlemen, I am going to begin, not with an apology† exactly, but something a little like one. It is no fault of mine in the matter, but I am afraid I shall find it difficult to make you hear me this evening on account of the acoustic character

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*A Lecture delivered at the International Electrical Exhibition of the Franklin Institute, September 25, 1884.

† The peculiarly bad acoustic character of the lecture-room, made it necessary to speak in short and disjointed sentences, with many repetitions, in order to be understood at all by the remoter portions of the audience. The lecturer hopes that the reader will make due allowance for this, as accounting for the awkward literary form of the address.

of the room. I will do my best, however, and that is all any man can do.

The subject I am to speak about I am sure will interest you. The sun is the life of us all; it keeps the world going. All terrestrial energy is but solar energy at second-hand. I will not discuss this evening the distance of the sun, its dimensions, etc., and the methods of ascertaining them, although I might make a very interesting lecture from that point of view, but I will begin at once by stating a few facts, which are essential to an understanding of the sun's constitution.

In the first place, then, the size of the sun is something enormous, absolutely beyond our power of conception. It is a great ball about eight hundred and sixty thousand miles in diameter, or one hundred and ten times the diameter of the earth. Perhaps that means nothing to you; but just for a moment imagine yourself in the centre of the sun, if it were possible for you to live there. Suppose the earth were placed in the centre of the sun where would the moon come? Why, it would only be a little more than half way to the solar surface. If the earth were at the centre of the sun, the moon would circle around the earth about half way from the centre of the sun to its surface. The radius of the sun is about four hundred and thirty thousand miles, and the distance of the moon from the earth is only two hundred and forty thousand miles, so that if we lived in the centre of the sun, its shell would make an admirable sky for all the lunar motions. Next, the sun is about a million and a quarter times the bulk of the earth. Take one million three hundred thousand earths and roll them into one ball and it would make a sphere about the size of the sun; but, the sun is not correspondingly massive, for it is only about three hundred and thirty thousand times as heavy as the earth. It follows, of course, that it is not as dense as the earth; it is only about one quarter as dense, or a little more than the density of water. A bushel of sun would weigh only about a quarter as much as an average bushel of the earth.

The sun, therefore, cannot well be a solid substance; it is not a ball of rock like the earth, but probably a great bubble as we shall see further on; a mass of gases surrounded by a shell of cloud.

Its power of attracting bodies is very great of course, because its mass is so enormous. On the surface of the sun a body would weigh nearly twenty-eight times as much as on the earth, so that if I were on the surface of the sun I should be crushed. I could hardly lift

my hand to my head for the force of gravity would be twenty-eight times as strong as it is here, and it would increase the weight so that a pound here would weigh twenty-eight pounds there. Of course you will see at once that this is a very important fact, as bearing on the constitution of the sun.

The solar ball rotates upon its axis just as the earth does, but more slowly. The earth turns around in twenty-four hours, but it takes the sun about twenty-five days to make one rotation. Now a very characteristic thing in regard to the sun's rotation is that it does not go all together; the equator of the sun, or its central zone, makes its circuit in about twenty-five days, but at a point half way to the poles it takes some twenty-seven days, or two days longer. It is as if the day on the earth at the mouth of the Amazon river were about two hours shorter than at the mouth of the St. Lawrence. The revolution of the sun's equator is more rapid than that of other portions, so that different portions of the sun appear to drive by each other like eddies in a stream. The sun's surface is not a solid mass, but like clouds, and the different portions are not coherent or strongly attached to each other.

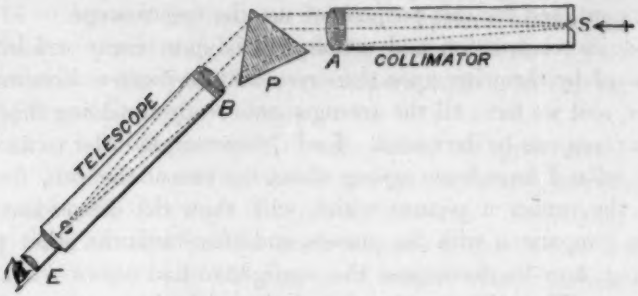
What we know about the sun comes almost entirely by the way of its radiance, or the light and heat, that it sends us. I am not going to give you a lecture on the nature of this radiance; a far more competent authority, Sir William Thomson, will treat that subject in the Academy of Music next Monday night. But I suppose you all know that the energy of the sun reaches us almost entirely in the form of waves, somewhat like the undulations of sound, which start from the sun and reach us here just as the waves of sound go through the air from me to you. These waves of solar radiance differ from each other only in the same kind of way that sound waves differ; in pitch and energy, but in nothing else. There is no proper distinction between sun-heat and sunlight, they are only different forms of the same action. The same radiance precisely, if it falls on my eye will make me see, and if it falls on a black sheet of paper will make it warm; while if it falls on a chemically prepared plate it will produce a picture by its chemical action. There is no line of distinction to be drawn between the light, heat and chemical rays. A few years ago it was believed that there were such differences, and the distinction still remains in some of our old text-books where you will find solar light, heat and chemical energy contrasted with each other in a way that is now known to be untrue and very mischievous.

The way to analyze sunlight is to take it to pieces by some form of instrument, and for this purpose we use the spectroscope.

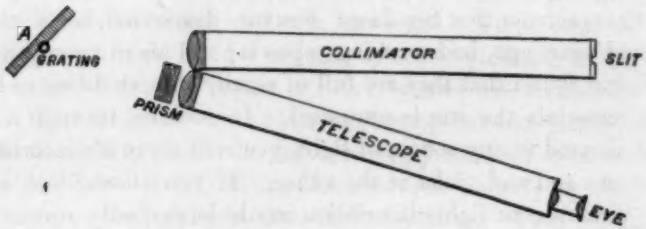
Now its construction and action will be most easily exhibited and explained by throwing upon the screen lantern-pictures illustrating the matter, and we have all the arrangements ready for doing this as soon as the room can be darkened. I will, however, in order to fix in your mind what I have been saying about the size of the sun, first show upon the screen a picture which will show the dimensions of the sun in comparison with the planets, and afterwards the other pictures, showing how we decompose the sunlight to find out of what the sun consists. While the room is being darkened I will say that this taking to pieces of sunlight and examining its parts and details is a comparatively new invention. It was found about seventy-five years ago that the spectrum that Sir Isaac Newton discovered, more than two hundred years ago, had markings upon it; and about twenty-five years ago it was found that they are full of significance, enabling us to tell of what materials the sun is composed. In looking through a spectroscope directed to any source of light, you will see in it a colored ribbon red at one end and violet at the other. If you should look at one of these incandescent lights the ribbon would be perfectly unmarked and smooth; but if the instrument were turned toward one of the arc lights the spectrum would be crossed by bright bands and lines; while if turned to the sun it would show a band marked by fine dark lines.

On this diagram now thrown upon the screen you have a representation of the sun with its planets around it drawn to scale. I presume you recognize the great planets Jupiter and Saturn and the earth we live on, so that you can get a true idea of the relative proportions of the sun and its attendant worlds; the earth you see, is a mere speck in space, although it affords room for a great many human beings.

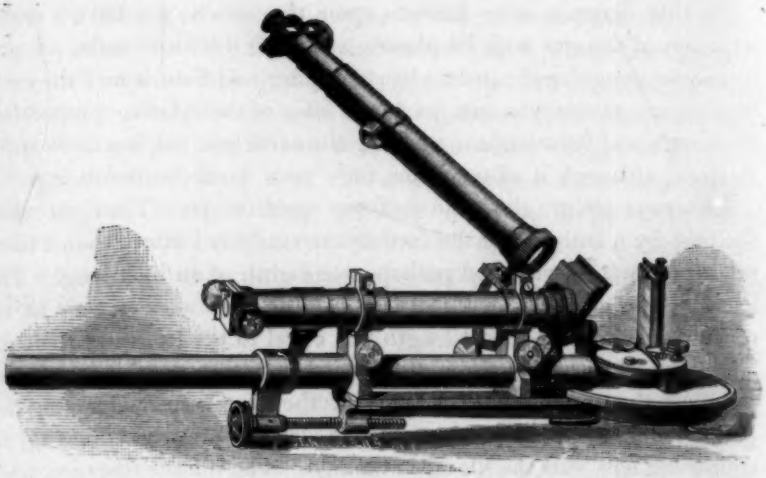
This next picture shows an ordinary spectroscope. The light enters the tube by a little slit at the further extremity not more than a thousandth of an inch wide and perhaps one-eighth of an inch long. This slit is at one end of a tube marked "collimator" as you see; at the other end is a lens of focal length just equal to the length of the tube. The light which passes through the slit has to traverse this lens before reaching the prism, and the effect of the lens is to render the rays parallel just as if they came from a star. Optically speaking, the collimator lens puts the slit off in the sky—at an infinite distance, while at the same time it leaves it at the ends of your fingers. The light



Arrangement of Prismatic Spectroscope.



Diffraction Spectroscope.



Princeton Spectroscope.

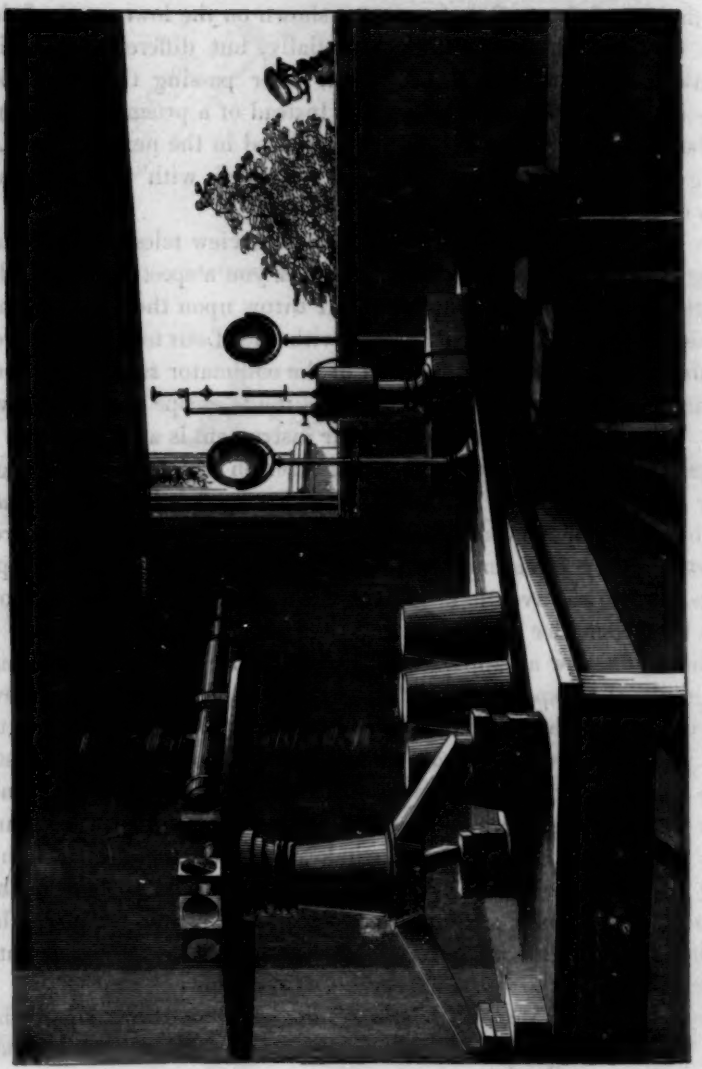
goes through a prism which changes its direction; then it goes to the view telescope and looking through that you see the ribbon of light.

In the second form of the apparatus shown on the lower part of the screen we have the same thing essentially, but different in detail. We have a collimator just as before, but after passing this the light strikes upon what is called the grating instead of a prism. There are some beautiful specimens of gratings exhibited in the next room. A grating consists of a flat polished mirror ruled with parallel lines drawn close together, many thousand in the inch.

The light then goes to the eye through the view telescope, and the grating produces the same effect and gives you a spectrum precisely as a prism would do. The instrument I throw upon the screen is the spectroscope which I use in Princeton with one of our telescopes there. The slit is here (pointing) at one end of the collimator tube; the grating stands upright at this place. Here is the telescope into which we look. The actual size of that particular instrument is about one and a half feet in length. I sometimes use another on which the collimator is four feet long, and the grating is six inches by five inches. It was ruled by Professor Rowland of Johns Hopkins University, Baltimore, with some eighty thousand lines, by a most beautiful and perfect apparatus of his own invention. That gives a longer spectrum than you obtain by the smaller instrument.

I show you now an apparatus which Mr. Lockyer uses in taking photographs of the spectrum. The light first comes through a window and passes through the further one of these two lenses and goes to where you see an electric lamp; then it passes through these lenses and to the spectrum; then through the prisms of the spectrum and thence to the camera box so that a photograph of the sunlight spectrum can be taken. You then shut the window and start the electric light, giving a spectrum which you can also photograph. If you put in the lamp a piece of iron or sodium or copper, you can thus compare the spectrum of sunlight with that of the substance which is put into the electric lamp.

Before showing Mr. Lockyer's results, I first throw upon the screen some spectrum photographs made by Professor Rowland. Here is a little portion of the blue part of the spectrum; the blue color is of course absent in the photograph. What I want you to notice line is the great number of lines. I have marked one "h"; that



General Arrangement of Spectrum Photographic Apparatus.

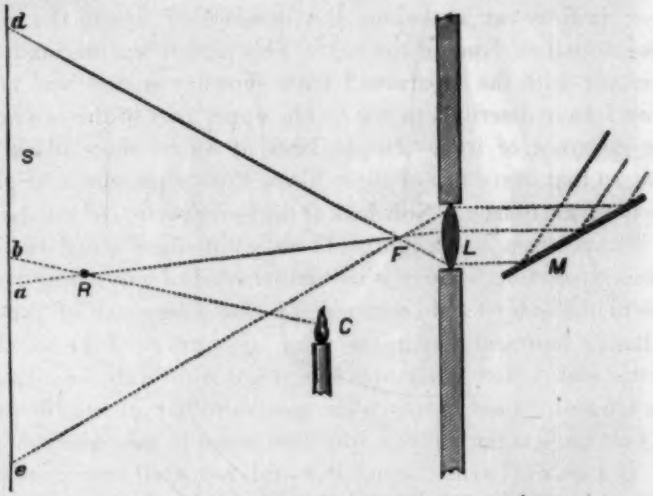
is due to hydrogen. This double line (pointing) is due to the presence of iron in the sun, and so of the other lines. We know the chemical elements which produce about half of these lines; the other half have not yet been identified. Now we show a piece of the green portion of the spectrum, a very important part of the spectrum it is too. This is interesting to photographers if there are any in this room; because all photographers know it is quite difficult to photograph green light. In that photograph it is possible to see about everything that it is possible to see by the naked eye in the spectrum. The photograph is so perfect that excepting only the color you can see all that can be brought out in the spectrum, by the most powerful instruments in use. One of these particular lines happens to interest me especially; that line (pointing) is the line which characterizes the spectrum of the corona. It is known as the 1,474 line, because it happened to come in that place in a map of the spectrum much used, made at an early date. It proves that the corona is largely a mass of floating gas.

By putting side by side the spectrum of the sunlight and the spectrum of iron we can determine the presence of iron in the sun, and here is original evidence of the fact. This picture was originally taken by Lockyer with the apparatus I have shown you, and was made in the way I have described to you. The upper part of this is a negative of the spectrum of iron. Bright lines of course show black in the picture, so that every one of these black lines represents a bright line in the spectrum of iron. Now look at the lower portion of the spectrum. That is a spectrum of sunlight. These white lines are dark lines in the solar spectrum. There is no further need of my telling you that iron is in the sun; for do you not see that every one of these iron lines has its representative in the solar spectrum? Take the three at the lower end. Here is a double line, it is double in the solar spectrum. There are many lines in this solar spectrum that are not lines of iron lines, but there is not an iron line that is not in the spectrum of the sun. If I should write "iron," it would not spell iron more plainly than do these lines. We have the same sort of evidence in relation to other materials, so that we can say with confidence that these metals exist in the sun.

I have not time to explain to you how bright lines in the spectrum become dark lines in the solar spectrum. If I take a vapor giving a spectrum of bright lines and put a stronger light behind it then these

bright lines will be reversed and they will immediately turn black, but I must not stop to tell you why.

This next slide gives you the catalogue of the solar elements so far as we know them. Iron, titanium, calcium, etc.; going down the list until you get to this point, there is not a substance known to exist in the sun that is not metallic. Nitrogen and chlorine do not show themselves there, carbon does not appear; many of the elements which are most powerful on the earth seem to be entirely wanting. What it means scientists cannot tell. There are many hypotheses, many theories, one being that the elements there represented are really more elementary, more difficult to be decomposed than nitrogen and chlorine; it being taken for granted that these elements are not elementary at all, but that they are decomposed by the great heat of the sun. We find metals and for the most part nothing else in the sun; perhaps sulphur is there, but probably not; oxygen, however, is probably present, indicating its presence very peculiarly by certain *bright* bands and lines first brought out by the photographs of Dr. Henry Draper some seven or eight years ago.



Method of Measuring the Intensity of Sunlight.

Passing now to the strength or intensity of sunlight, the picture before you is intended to show how we measure this. We find that the sunlight is equivalent to about one thousand five hundred and seventy-five billions of billions of candles, and this diagram roughly

represents the apparatus by which we determine that fact. It is done in this way; the sunlight shines on a mirror, and so is reflected into a room through a lens of known size, say one inch in diameter. The rays after passing the focus diverge and fall on the screen; if the image on the screen is ten feet, or one hundred and twenty inches in diameter, you will see that the light will be reduced fourteen thousand four hundred times; if we make the diameter of the disc twenty feet, we reduce the light a great deal more, four times as much; making it still larger, we reduce it more yet, and in that way we easily reduce the sunlight to the one hundred thousandth part of its natural strength. Now by moving the candle *C* we can get the shadow of the pencil *R*, cast by the sun shining through that lens, of the same darkness as that cast by the candle; and in that way we can compare sunlight with candlelight; and we find what I have before stated.

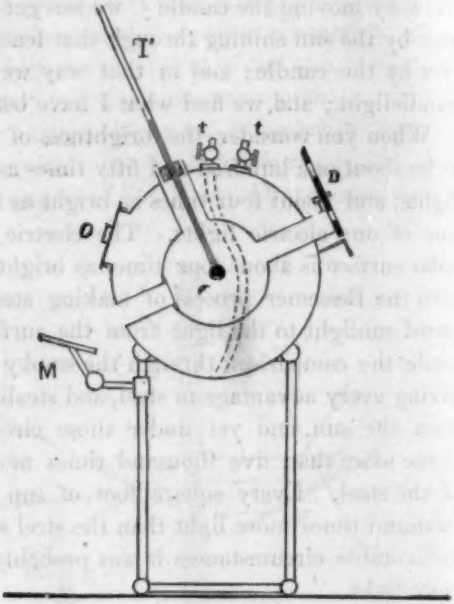
When you consider the brightness of the sun's surface you find it to be about one hundred and fifty times as bright as one of our calcium lights, and about four times as bright as the brightest of the points in one of our electric lights. The electric light is very bright, but the solar surface is about four times as bright as that. Some of you have seen the Bessemer process of making steel; Professor Langley compared sunlight to the light from the surface of the molten steel. He made the comparison through the smoky air of Pittsburgh purposely giving every advantage to steel, and stealing every advantage he could from the sun, and yet under those circumstances the solar surface shone more than five thousand times more brightly than the surface of the steel. Every square foot of sun was giving more than five thousand times more light than the steel surface; and considering the unfavorable circumstances it was probably giving ten thousand times more light.

Let us pass now to the consideration of the amount of the solar heat. One of the earliest apparatus for measuring it is shown here on the screen and is called a pyr-heliometer, *i. e.*, measurer of solar fire. It is a sort of snuff box of thin polished silver, blackened on the front surface and filled with water. In the box a thermometer bulb is placed, the mercury marker standing at the point "*d*." It is turned towards the sun, and the sun is allowed to shine on the upper surface of the box so as to warm the contained water, and it is observed how much the sun's rays will warm it in a given time. It is allowed to stand, say, five minutes to see how much change the temperature will change,

first with an umbrella over it to shut off the light, and then with the sun striking fully upon it, and thus we find how much a given beam of light will raise the temperature of a given weight of water.

Other forms of instruments are made. Here is one that Violle has used. It is a hollow sphere containing a thermometer around which water is circulated in a jacket. The sun is allowed to shine through the open space and the thermometer will rise until it is some 18 or 20 degrees higher than a thermometer outside. If you know just how much higher you can calculate just how much heat is received from the sun.

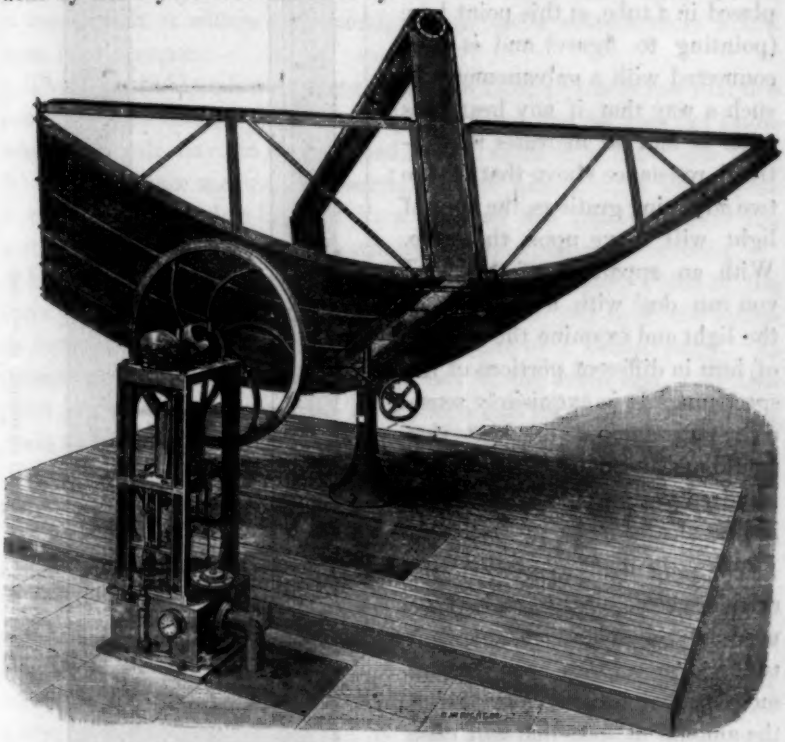
Pouillet's Pyrheliometer.



Violle's Actinometer.

The apparatus shown in this picture is a solar engine invented by Mr. Ericsson a year or two ago. It is possible to collect the sun's rays in a great mirror like that and throw them on a hollow tube of iron about six inches in diameter and twelve feet long and filled with water. The heat of the sun sets the water boiling and that is connected by a pipe with a steam engine which is thus driven by the solar heat. Upon thirty square feet of the earth's surface enough sun heat falls to give pretty nearly a continuous horse power, *i. e.*, if you could collect all the heat on that amount of surface you would have a horse-power

of heat, and this heat would enable you to drive an ordinary engine of about $\frac{1}{6}$ of a horse-power. During the present summer the haze in the air has diminished the effectiveness of the heat. You can see that an engine of that kind would be of considerable value in a rainless country like Egypt or our western regions, where very much work could be done by the rays of the sun directly.



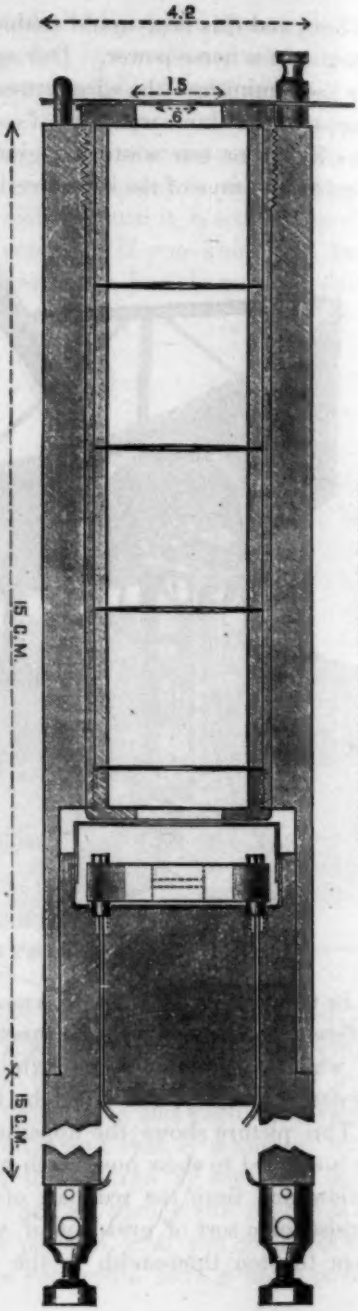
Ericsson's Solar Engine.

In many cases we want to know how much heat is brought from different portions of the solar spectrum. This is done by an apparatus of which a specimen is on exhibition here, invented by my friend Professor Langley, and called by him a bolometer.

This picture shows the apparatus of Professor Langley, by which he is enabled to show how much heat there is from the blue, from the yellow, and from the red part of the spectrum. The sensitive part consists of a sort of grid-iron of very thin strips of iron; the iron is from the ten thousandth to the twenty-five thousandth part of an

inch thick, and each strip is about $\frac{1}{40}$ of an inch wide and about $\frac{1}{2}$ inch long. On each side is a similar grid-iron. Without going into the electrical details I will simply say that this sensitive grid-iron is placed in a tube, at this point here (pointing to figure) and is then connected with a galvanometer in such a way that if any heat falls upon it and so increases its electrical resistance above that of the two adjoining gratings, the spot of light will move upon the scale. With an apparatus of this kind you can deal with a spectrum of the light and examine the amount of heat in different portions of the spectrum. It is exquisitely sensitive; an amount of heat that would melt a pound of ice in five hundred years would be distinctly indicated.

The amount of heat given to the earth's surface by the sun is measured by the solar constant, it is twenty-five calories per square metre per minute, the calory being the amount of heat that will raise one kilogram of water one centigrade degree in temperature. Every square foot of the sun's surface is throwing off heat enough to be equivalent to about ten thousand horse-power. All the machinery at this exhibition could be run by one square foot of the sun's surface. I would not want a larger fortune than the control of one foot of the sun's surface; it



Section of Bolometer Case and Bolometer.

would run a two thousand horse-power engine, year in and year out. The heat of the sun would thaw its way through a crust of ice about fifty feet thick in one minute of time, covering the whole surface of the sun. If I had a column of ice two and a quarter miles in diameter, and reaching the whole distance from here to the sun, and if I could by any means bring the whole solar heat to bear directly upon the ice, it would melt it within one second, and in seven seconds more would turn it into vapor.

This is probably a low estimate; Professor Langley has shown that this estimate of 25 calories will have to be increased, but he does not know whether it will have to be reckoned a little more or a little less than 30 to each square meter. The earth receives heat enough every year from the sun to melt a layer of ice a hundred feet thick all over the earth's surface if this heat were wholly expended upon ice-melting.

I now pass to the consideration of the sun's surface. One of the ways of studying that is by photograph. I show you upon the screen an instrument used at the last transit of Venus by a British party. It consists of a telescope with a camera box at the lower end. At this point is arranged an apparatus by which a slit in a plate of metal is made to flash across in front of the photographic plate on touching a trigger. That allows the sunlight for a moment to shine on the plate and make the picture.

Here is a picture taken by a similar instrument in 1869 at the time of the eclipse. I throw it on the screen, not so much to show the sun itself as to exhibit the contrast between the edges of the sun and the moon. The edge of the moon is very sharp and irregular. There are mountains on it a mile or two high; now the edge of the sun is very much more softened off. The edge of the moon is rocky, hard and flinty, but the edge of the sun is like wool or clouds. Here you see a sun spot and what is called a facula. You will also of course see a spider line across the picture to indicate east and west.

Here is a picture of the whole sun taken in 1872, by Rutherfurd of New York, in which you see many interesting points on the sun's surface. You will notice the darkening of the edge of the sun. As soon as you begin to make measurements of the brightness of the sun, you find that the centre is nearly four times as bright as the edge, and in the blue portion of the spectrum the difference is still greater. Those bright streaks are the so-called faculæ or "little torches" as the word means. At the time this was taken the spots were very large and

numerous. They lie in two belts, and one of them is very marked on this picture. The axis of the sun lay in that direction; here is one of the zones of spots and the other is here. We shall of course see the characteristics of the spot better as we study them in detail. Here is a smaller picture magnified very much. The other plate was about the size it was originally taken; but this one is enlarged, some twenty or thirty times, as shown by this photograph. The sun's surface looks rough like drawing paper; it is not a smooth surface such as water would present, but it is in all probability a surface of clouds. You see here a dark ground-work scattered with brighter granules; at this point you see one spot nearly round, and here we have a group just breaking out with the penumbra partially formed, but not surrounding them symmetrically as yet.

The photography of the sun has been carried further in France than in any other country. Here is one of Janssen's pictures. On that scale the sun would be about two hundred feet in diameter. You can see here the form and character of the granules on the solar surface. You will notice that in one place that the granules are nearly round; they look like finger tips turned towards you. In this corner on the other hand they are lying sideways toward you and appear much elongated. There is a spot in process of formation. Here is another place where the filaments are disturbed. Janssen found that if you take a pair of these pictures, at an interval of one minute, they would very nearly agree in all particulars, but if an hour or more should elapse between the pictures they would differ enormously; and remember that every one, even of these smallest granules, is two or three hundred miles in diameter. The surface of the sun seems to be made up of cloud-like masses floating in a gaseous atmosphere and I have no doubt that is the fact. Professor Langley compares the appearance of the surface of the sun to snow flakes on a gray overcoat, and an English physicist has said that it looks like pea soup.

Sometimes we wish to study the sun with the eye instead of by photograph. The photograph of course tells no lies, but it gives merely a brutal copy of what can be seen at any particular moment. With the eye you can look leisurely and can study what you see. The sunlight is so bright, however, that you must find some means of diminishing it. The apparatus now shown on the screen is the best for that purpose. It is known as a helioscope. The little thing is about five inches in diameter and five or six inches long. Here the

sunlight enters; it is reflected at this first surface of glass, most of the light goes through the glass, but a little is reflected strike and this second surface; most of that light goes through again and the remainder is reflected. We first throw away nine-tenths of the light and then throw away nine-tenths of what is left. The remainder is reflected to another mirror of black glass; it is again reflected, and thus suffering four reflections before reaching the eye, each reflection at the angle of polarization. The upper box turns round upon the lower; when I turn one at right angles to the other I can cut the light entirely off, but when they are turned so that the mirrors are all parallel to each other the light is quite bright; so that by turning the upper box I have all the degrees of brightness. You thus see the solar surface with the greatest ease and comfort. We do not cut down the size of the lens, but let the whole light come through and then throw away what we do not want, saving enough for vision. I ought to say here that it is a mistake to cap the object glass of the telescope in order to diminish the light; sometimes you have to do it if you have not a proper eye-piece; but the definition is never so good on account of diffraction effects, and with such a helioscope as I have described, there is no difficulty in observing the sun with the whole 23 inches of aperture of our Princeton telescope.

Sun Spot of March 5, 1873, (after Langley.)

Here is a telescopic view with a lower power which shows another spot with the faculæ. The granules on the surface of the sun are shown nearly as well as by the photographs. Here is a picture by Professor Langley, the first of his pictures. I show it upon the screen because it gives you a more minutely accurate view of the solar surface than any other picture I know of. You notice this square in the corner, that is six thousand miles on a side, and the little markings in it are portraits. He very carefully depicted all the individual granules that appeared in these squares so that you get the actual shape and the size of what appeared at that time. The rest of the surface he made to agree in a general way with what you see in these squares. It takes a very large telescope not less than ten or twelve inches aperture, and under favorable circumstances to bring out distinctly what you see in this picture.

Spot of July 16, 1866. (Secchi.)

Here is a picture of a sun spot made at Berlin a year or two ago. When we come to examine a sun-spot we find that it has characteristic shapes at different ages. An old one is usually nearly round, but a new one like this is irregular. The central portion is dark, but not uniformly so. You will notice in the centre some dark holes (known as Dawe's holes) much darker than the rest, even of the umbra; around it is what we call the penumbra.

(To be concluded.)

ON THE FRITTS SELENIUM CELLS AND BATTERIES.*

By C. E. Fritts.

In all previous cells, so far as I am aware, the two portions or parts of the selenium, at which the current enters and leaves it, have been in substantially the same electrical state or condition. Furthermore, the paths of the current and of the light have been transverse to each other, so that the two forces partially neutralize each other in their action upon the selenium. Lastly, the current flows through not only the surface layer which is acted upon the light, but also through the portion which is underneath and not affected thereby, and which therefore detracts from the actual effect of the light upon the selenium at the surface.

My form of cell is a radical departure from all previous methods of employing selenium, in all of these respects. In the first place, I form the selenium in very thin plates, and polarize them, so that the opposite faces have different electrical states or properties. This I do by melting it upon a plate of metal with which it will form a slight chemical combination, sufficient, at least, to cause the selenium to adhere and make a good electrical connection with it. The other surface of the selenium is not so united or combined, but is left in a free state, and a conductor is subsequently applied over it by simple contact or pressure.

During the process of melting and crystallizing, the selenium is compressed between the metal plate upon which it is melted and another plate of steel or other substance with which it will not combine. Thus, by the simultaneous application and action of heat, pressure, chemical affinity and crystallization, it is formed into a sheet of granular selenium, uniformly polarized throughout, and having its two surfaces in opposite phases as regards its molecular arrangement. The non-adherent plate being removed after the cell has become cool, I then cover that surface with a *transparent conductor of electricity*, which may be a thin film of gold leaf. Platinum, silver, or other suitable material may also be employed. The whole surface of the selenium is therefore covered with a good electrical conductor, yet is practically bare to the light, which passes through the conductor to

* Paper read before the American Association for the Advancement of Science, at Philadelphia, Sept. 5, 1884.

the selenium underneath.* My standard size of cell has about two by two and a half inches of surface, with a thickness of $\frac{1}{1000}$ to $\frac{5}{1000}$ inch of selenium. But the cells can of course be made of any size or form. A great advantage of this arrangement consists in the fact that it enables one to apply the current and the light to the selenium in the same plane or general direction, instead of transversely to each other as heretofore done, so that I can cause the two influences to either coincide in direction and action or to act upon opposite faces of the selenium and oppose each other, according to the effect desired.

By virtue of the process and arrangement described, my cells have a number of remarkable properties, among which are the following:

1. *Their Sensitiveness to Light* is much greater than ever before known. The most sensitive cell ever produced, previous to my investigations, was one made by Dr. Werner Siemens, which was 14·8 times as conductive in sunlight as in dark. In Table A, I give results obtained from a number of my cells.

TABLE A.—*Sensitiveness to Light.*

Selenium cell.	Battery power.	Resistance in dark.	Resistance in sunlight.	Ratio.
No. 22.....	5 elements	39,000 ohms	340 ohms	114· to 1
No. 23*.....	5 "	14,000 "	170 "	82·3 "
No. 24†.....	5 "	648,000 "	2,400 "	270· "
No. 25*.....	5 "	180,000 "	930 "	196·5 "
No. 26*.....	5 "	135,000 "	710 "	190· "
No. 107.....	5 "	118,000 "	740 "	159· "
No. 108.....	5 "	200,000 "	900 "	222· "
No. 122.....	5 "	56,000 "	220 "	254·5 "
No. 129*.....	5 "	200,000 "	940 "	212· "
No. 137.....	5 "	108,000 "	320 "	337·5 "

* Cells No. 23 and No. 129 are now in possession of Prof. W. Grylls Adams, of Kings College, London; Dr. Werner Siemens has No. 25, and Prof. George F. Barker, of Philadelphia, has No. 26.

† No. 24 was measured with a bridge multiplier of 6 to 1.

It will be observed that I have produced one cell, which was 337·5 times as conductive in hazy sunlight as in dark. The tremendous

* The method of constructing the cells is described in the *Scientific American Supplement*, No. 462, for Nov. 8, 1884, translated from *La Lumiere Electrique*.

change of resistance involved in the expression "337·5 times" may, perhaps, be more fully realized by saying that 99·704 *per cent.* of the resistance had disappeared temporarily, under the joint action of light and electricity, so that there remained *less than* $\frac{3}{10}$ *of 1 per cent. of* the original resistance of the selenium in dark.

In order to obtain these maximum results, the cells must be protected from light when not in use. The resistance is first measured while the cell is still in total darkness. It is then exposed to sunlight, and again measured. It is also necessary to send the current in at the gold electrode or face, as the cell is much less sensitive to light when the light acts upon one surface of the selenium and the current enters at the opposite surface. When the two influences, the light and the current, act through the gold, in conjunction, their forces are united; and, as every atom of the selenium is affected by the light, owing to the extreme thinness of the plate, we have the full effect shown in the measurements.

Cells which are sensitive to light improve by being used daily, and their sensitiveness becomes less if they are laid aside and not used for a considerable length of time, especially if allowed to become overheated. They should be kept cool, and exposed to light frequently, whether they are used or not.

Mode of Measuring Cells.—So great is the sensitiveness of these cells to external influences, that it is necessary to adopt some particular system in measuring their resistance, and to adhere strictly to that system, as every change in the method of measurement produces a difference in the result, and the different measurements would not be comparable with each other. The reason for this will be explained presently.

The system I have adopted is the Wheatstone's bridge arrangement, with equal sides—never using multipliers in measurements for comparisons. In each multiplier wire I have 500 ohms resistance. When the bridge is balanced, one-half of the current flows through the cell and acts upon the selenium. Between the bridge and the cell is a reversing switch, so that the current can be reversed through the cell without changing its course through the bridge. A Bradley tangent galvanometer is used, employing the coil of 160 ohms resistance. The Leclanché battery is exclusively used in measurements for comparison.

2. *The Kind of Battery Employed* has a marked effect upon the sensitiveness to light, which is largely reduced or entirely destroyed when the bichromate battery is used. The same cells again become

extremely sensitive with the Leclanché battery. We might, perhaps, expect that a change in the current employed would cause a change in the *resistance* of a cell, but it is not clear how or why it should affect the *sensitiveness of selenium to light.*

"If one kind of battery current destroys its sensitiveness, may we not suppose that another kind might increase its sensitiveness? Although the Leclanché has operated well, some other may operate still better, and by its special fitness for use on selenium cells may intensify their actions, and so bring to light other properties yet unthought of. Is not here a promising field for experiment, in testing the various forms of battery already known, or even devising some new form especially adapted to the needs and peculiarities of selenium cells?"

One year ago I made the foregoing suggestions in a paper on "*A New Form of Selenium Cell,*" presented before this Association at Minneapolis. I am now at liberty to state that my photo-electric battery, presently to be described, marks an advance in the direction indicated. The current from this battery increases the sensitiveness of the cells to light, and also to reversal of current. One cell whose highest ratio in light was about 83 to 1, with the Leclanché battery, when measured with my battery gave a ratio of 120 to 1. It seems to make the resistance of the cell both higher in dark and lower in sunlight than with the Leclanché battery. But the field is still open to others for the discovery of a battery which may be still better.

3. *The Two Surfaces of the Selenium Act Differently Towards Currents* sent into them from the contiguous conductors. One surface offers a higher resistance to the current than the other. The former I utilize as the anode surface, as I have found that the cell is more sensitive to light when the current enters at that surface, which is ordinarily the one covered by the gold or other transparent conductor. Some cells have this property but feebly developed, but in one instance the resistance offered to the current by the anode surface was 256 times as high as that offered by the cathode surface to the same current. In the majority of cases, however, the ratio does not exceed ten times. Table B gives some recent results, all measurements being made in the dark.

The direction of the current is always indicated by stating the position of the gold electrode, by the terms "gold anode," and "gold cathode."

TABLE B.—*Sensitiveness to Reversal of Direction of Current.*

No. of cell.	Battery.	Resistance, "gold anode."	Resistance, "gold cathode."	Ratio.
⅜ inch square, No. 4.....	5 elements	20,000 ohms	1,000 ohms	20· to 1
⅜ " " No. 3.....	8c. cell	6,500 "	400 "	16·2 "
Full size, No. 13.....	1 element	9,000 "	800 "	11·2 "
" No. 14.....	5 "	2,440 "	130 "	18· "
" No. 15.....	5 "	4,640 "	210 "	22· "
" No. 27.....	5 "	6,900 "	440 "	16· "
" No. 126	1 "	5,000 "	330 "	15· "

4. *Sensitiveness to Change of Battery Power.*—My cells are extremely sensitive to any change in the strength or character of the current flowing through them, which is shown by a corresponding change in the resistance of the cell. I can therefore vary the resistance of one of my cells in many ways, and the following may be specified:

(a.) By changing the potential or electromotive force of the current through the cell.

(b.) By changing the "quantity" of the battery or current.

(c.) By putting more or less resistance in the circuit.

(d.) By dividing the current by one or more branch circuits or shunts around the cell.

(e.) By varying the resistance in any or all of said circuits.

A cell whose resistance becomes greater as the battery power becomes greater, and *vice versa*, I call an "*L B* cell," signifying *Like the Battery power*. A "*U B* cell" is one whose resistance becomes greater as the battery power (or strength of current) becomes less, and *vice versa*, being *Unlike the Battery power*, or current strength.

These changes of resistance are not due to heating of the conductor or the selenium, and the following instance will illustrate this. I have one cell in which the selenium has about ¼ inch square of surface, melted on a brass block nearly one inch thick. This cell measured, with 25 elements of Leclanché, 40,000 ohms. On changing the battery to 5 elements, the resistance fell instantly to 30 ohms, and there remained. On again using the current from 25 elements, the resistance instantly returned to 40,000 ohms. Had these results been due in any degree to heating, the resistance would have changed gradu-

ally as the heat became communicated to the brass, whereas no such change occurred, the resistances being absolutely steady. Moreover, even the fusion of the selenium would not produce any such change.

The "*U B*" property does not ordinarily change the resistance of the cell to exceed ten times, *i. e.*, the resistance with a weak current will not be over 10 times as high as with a strong one. But I have developed the "*L B*" property to a far higher degree. Table C gives some recent results obtained with *L B* cells, including one whose resistance, with 25 elements Leclanché, was 11,381 times as high as with 8 elements, and which, after standing steadily at 123 ohms (and then at 325 ohms with one element), on receiving the current from 25 elements again returned to its previous figure of 1,400,000 ohms.

TABLE C.—*Sensitiveness to Change of Battery Power.*

No. of Cell.	Resistance with 25 elements.	Resistance with 5 elements.	Ratio of Change.
⅜ inch square, No. 1	40,000 ohms.	30 ohms.	1,333· to 1
⅜ " " No. 2	13,000 "	40 "	325· "
¼ " " No. 1	1,400,000 "	123* "	11,381· "
½ " " No. 2	500,000 "	62 "	8,064· "
⅛ " " No. 5	3,500 "	21 "	167· "
Full size, No. 81	68,000 "	121 "	561· "
" " No. 82	9,000 "	64 "	140· "
" " No. 83	17,300 "	74 "	233· "
" " No. 119	35,600 "	19 "	1,894· "

* This measurement was obtained with eight elements.

The results in the table were obtained by changing the strength of current by throwing in more or less of the battery. Like results can be obtained by varying the current through the cell by any of the other methods before specified. All of the measurements were in the dark.

5. *Dual State of Selenium.*—My cells, when first made, seem to have two states or conditions. In one, their resistance is very low, in the other it is very high. When in the low state they are usually not very sensitive, in any respect. I therefore raise the resistance, by sending an intermittent or an alternating current through the cells, and in their new condition they at once become extremely sensitive to light,

currents and other influences. In some cases they drop to the low state again, and require to be again brought up, until, after a number of such treatments, they remain in the sensitive state. Occasionally a cell will persist in remaining in the insensitive state. The before-mentioned treatment raises it up for a moment, but, before the bridge can be balanced and the resistance measured, it again drops into the low or insensitive state. Some cells have been thus stimulated into the high or sensitive state repeatedly, and every means used to make them stay there, but without avail, and they have had to be laid aside as intractable.

In the earlier stages of my investigations, before the discovery of this dual state and of the method of changing a cell from the insensitive to the sensitive condition, hundreds of cells were made, finished, and tested, only to be then ruthlessly destroyed and melted over, under the impression that they were worthless. Now, I consider nothing worthless, but expect sooner or later to make every cell useful for one purpose or another.

The most singular part of this phenomenon is the wide difference in the resistance of the cells in the two states. In the low state it may be a few ohms, or even a few hundredths of an ohm. In the high state, it is the normal working resistance of the cell, usually between 5,000 and 200,000 ohms, but is often up among the millions. The spectacle of a little selenium being stimulated, by a few interruptions of the current through it, into changing its resistance from a fraction of an ohm up to a million or several millions of ohms, and repeatedly and instantly changing back and forth, up and down, through such a wide range—we might almost say, changing from zero to infinity, and the reverse, instantly—is one which suggests some very far-reaching inquiries to the electrician and the physicist. What is the nature of electrical conductivity or resistance, and how is it so greatly and so suddenly changed?

6. *Radio-electric Current Generators.*—My cells can be so treated that they will generate a current by simple exposure to light or heat. The light, for instance, passes through the gold and acts upon its junction with the selenium, developing an electromotive force which results in a current, proceeding from the metal back, through the external circuit, to the gold in front, thus forming a photo-electric dry couple or battery. It should preferably be protected from overheating, by an alum water cell or other well-known means.

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The current thus produced is radiant energy converted into electrical energy directly and without chemical action, and flowing in the same direction as the original radiant energy, which thus continues its course, but through a new conducting medium suited to its present form. This current is continuous, constant, and of considerable electromotive force. A number of cells can be arranged in multiple arc or in series, like any other battery. The current appears instantly when the light is thrown upon the cell, and ceases instantly when the light is shut off. If the light is varied properly, by any suitable means, a telephonic or other corresponding current is produced, which can be utilized by any suitable apparatus, thus requiring no battery but the selenium cell itself. The strength of the current varies with the amount of light on the cell, and with the extent of the surface which is lighted. I produce current not only by exposure to sunlight, but also to dim diffused daylight, to moonlight, and even to lamplight. I use this current for actual working purposes; among others, for measuring the resistance of other selenium cells, with the usual Wheatstone's bridge arrangement, etc., before described. I have also used it for signaling, for telephonic and similar purposes. Its use for photometric purposes, and in current-regulators will be mentioned further on. It is undoubtedly available for all uses for which other battery currents are employed, and I regard it as the most constant, convenient, lasting, readily used and easily managed pile or battery of which I have any knowledge. On the commercial scale, it could be produced very cheaply, and its use is attended by no expense, inasmuch as no liquids or chemicals are used, the whole cell being of solid metal, with a glass in front, for protection against moisture and dust. It can be transported or carried around as easily and safely as an electro-magnet, and as easily connected in a circuit for use wherever required. The current, if not wanted immediately, can either be "stored" where produced, in storage batteries of improved construction devised by me, or transmitted over suitable conductors to a distance, and there used, or stored as usual till required.

7. *Singing and Speaking Cells.*—When a current of electricity flowing through one of my selenium cells is rapidly interrupted, a sound is given out by the cell, and that sound is the tone having the same number of air variations per second as the number of interruptions in the current. The strength of the sound appears to be independent of the direction of the current through the cell. It is produced on the face of the cell, no sound being audible from the back of the cell. An

alternating current also produces a sound corresponding to the number of changes of direction. Experiments also show that, if a telephonically undulating current is passed through the cell, it will give out the speech or other sound corresponding to the undulations of the current, and furthermore, that the cell will sing or speak in like manner without the use of a current, if a suitably varied light is thrown upon it while in closed circuit.

My experiments having been devoted especially to those branches of the subject which promised to be more immediately practically valuable, I have not pursued this inquiry very far, and offer it for your consideration as being not only interesting, but possibly worthy of full investigation.

General Observations on the Properties of Cells.—From the number of different properties possessed by my cells, it might be anticipated that the different combinations of those properties would result in cells having every variety of action. This is found to be the case. As a general rule, the cells are noteworthy in one respect only. Thus, if a cell is extremely sensitive to light, it may not be specially remarkable in other respects. As a matter of fact, however, the cells most sensitive to light are also "*U B* cells."

The property of sensitiveness to light is independent of the power to generate current by exposure to light—the best current-generating cells being only very moderately sensitive to light, and some of the most sensitive cells generate scarcely any current at all. Current-generating cells are, almost without exception, "*U B* cells," and the best current-generating cells are strongly polarized, showing a considerable change of resistance by reversing the direction of a current through them; and they are also strong "anode cells," *i.e.*, the surface next to the gold offers a higher resistance to a battery current than the other surface of the selenium does. The power to generate a current is temporarily weakened by sending a battery current through the cell while exposed to light, in either direction. The current generated by exposure to light is also weakened by warming the cell, unless the cell is arranged for producing current by exposure to heat.

The properties of sensitiveness to light and to change of battery power are independent of each other, as I have cells which are sensitive to change of current but absolutely insensitive to light, their resistance remaining exactly the same whether the cells are in darkness or in sunlight. I also have cells which are sensitive to light, but

are unaffected by change of battery power or by reversing the direction of the current through them.

The sensitiveness to change of battery power is also independent of the sensitiveness to reversal of direction of the current. Among the best "*L B* cells" some are "anode cells" and others are "cathode cells," while still others are absolutely insensitive to reversal of current or to the action of light.

Constancy of the Resistance.—A noticeable point in my cells is the remarkable constancy of the resistance in sunlight. Allowing for difference in the temperature, the currents, and the light, at different times, the resistance of a cell in sunlight will remain practically constant during months of use and experiments, although during that time the treatments received may have varied the resistance in dark hundreds of thousands of ohms—sometimes carrying it up and at others carrying it down again, perhaps scores of times—until it is "matured," or reaches the condition in which its resistance becomes constant.

As has already been stated, the sensitiveness of a cell to light is increased by proper usage. This increased sensitiveness is shown, not by a lowered resistance in light, but by an increased resistance in dark. This change in the cell goes on, more or less rapidly, according as it is retarded or favored by the treatment it receives, until a maximum is reached, after which the resistance remains practically constant in both light and dark, and the cell is then "matured" or finished. The resistance in dark may now be 50 or even 100 times as high as when the cell was first made, yet whenever exposed to sunlight it promptly shows the same resistance that it did in the beginning. The various treatments, and even accidents, through which it has passed in the meantime, seem not to have stirred its molecular arrangement under the action of light, but to have expended their forces in modifying the positions which the molecules must normally assume in darkness.

Practical Applications.—There are many peculiarities of action occasionally found, and the causes of such actions are not always discernible. In practice I have been accustomed to find the peculiarities and weaknesses of each cell by trial, developing its strongest properties and avoiding its weaknesses, until, when the cell is finished, it has a definite and known character, and is fitted for certain uses and a certain line of treatment, which should not be departed from, as it will

be at the risk of temporarily disabling it. In consequence of the time and labor expended in making cells in the small way, testing, repairing damages done during experiments, etc., the cost of the cells now is unavoidably rather high. But if made in a commercial way, all this would be reduced to a system, and the cost would be small. I may say here that I do not make cells for sale.

The applications or uses for these cells are almost innumerable, embracing every branch of electrical science, especially telegraphy, telephony and electric lighting, but I refrain from naming them. I may be permitted, however, to lay before you two applications, because they are of such general scientific interest. The first is my

Photometer.—The light to be measured is caused to shine upon a photo-electric current-generating cell, and the current thus produced flows through a galvanometric coil in circuit, whose index indicates upon its scale the intensity of the light. The scale may be calibrated by means of standard candles, and the deflections of the index will then give absolute readings showing the candle.power of the light being tested. Or, the current produced by that light and that produced by the standard candle may be compared, according to any of the known ways of arranging and comparing different lights—the cell being lastly exposed alternately to the two lights, to see if the index gives exactly the same deflection with each light.

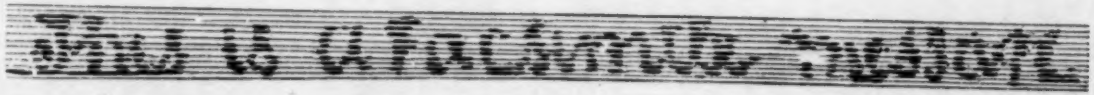
This arrangement leaves untouched the old difficulty in photometry, that arising from the different *colors* of different lights. I propose to obviate that difficulty in the following manner: As is well known, gold transmits the green rays, silver the blue rays, and so on; therefore, a cell faced with gold will be acted upon by the green rays, one faced with silver by the blue rays, etc. Now if we construct three cells (or any other number) so faced that the three, collectively, will be acted upon by all the colors, and arrange them around the light to be tested, at equal distances therefrom, each cell will produce a current corresponding to the colored rays suited to it, and all together will produce a current corresponding to all the rays emitted by the light, no matter what the proportions of the different colors may be. The three currents may act upon the same index, but each should have its own coil, not only for the sake of being able to join or to isolate their influences upon the index, but also to avoid the resistances of the other cells. If a solid transparent conductor of electricity could be found which could

be thick enough for practical use and yet would transmit all the rays perfectly, *i. e.*, transmit white light unchanged, that would be still better. I have not yet found a satisfactory conductor of that kind, but I think the plan stated will answer the same purpose. This portion of my system I have not practically tested, but it appears to me to give good promise of removing the color stumbling-block which has so long defied all efforts to remove it, and I therefore offer it for your consideration.

Photo-electric Regulator.—My regulator consists of a current-generating cell arranged in front of a light, say, an electric lamp whose light represents the varying strength of the current which supports it. The current produced in the cell by this light flows through an electro-magnetic apparatus by means of which mechanical movement is produced, and this motion is utilized for changing resistances, actuating a valve, rotating brushes, moving switches, levers, or other devices. This has been constructed on a small scale and operates well, and I think it is destined to be largely used, as a most sensitive, simple and perfect regulator for currents, lights, dynamos, motors, etc., whether large or small.

In conclusion, I would say that the investigation of the physical properties of selenium still offers a rare opportunity for making very important discoveries. But candor compels me to add that whoever undertakes the work will find it neither an easy nor a short one. My own experience would enable me to describe to you scores of curious and suggestive results, but lack of time prevents my giving more than this very incomplete outline of my discoveries.

PRESENT CONDITION OF KRAKATOA.—Messieurs Brêhn and Korthals have recently visited Krakatoa and given an account of the volcanic action. At some distance from the island, clouds of vapors seemed to hover over the crater, which suggested the existence of fumeroles; but on approaching with a canoe, they found that what they had taken for a vapor was nothing but dust, produced by a continual bombarding of projectiles of every magnitude, which fell from the summit. There are numerous layers of rocks, separated by small beds of sandy tufa, which are so common in all volcanic countries. The rocks appeared to belong to the family of basalts. The present eruption was accompanied by very acid pumice, containing 72 per cent. of silex, with plagioclase, bronzite and magnetite. The original material, which by its gaseous emulson produced the pumice, is a bottle-green glass, bits of which are found in the pumice beds.—*Comptes Rendus*, Aug. 25, 1884. C.



SYNCHRONOUS
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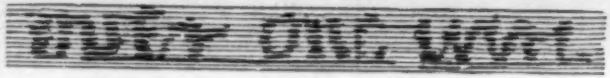

DELANY'S FAC-SIMILE TELEGRAPHIC TRANSMISSION.

By Prof. Edwin J. Houston.

It will doubtless interest the readers of the JOURNAL to learn that Mr. P. B. Delany, the inventor of the first successful synchronous-multiplex telegraphic system, has fulfilled the promise he made a long time ago, and has practically applied his invention to fac-simile transmission, whereby the hand-writing of a correspondent, pen sketches, maps, plans, hieroglyphics, etc., can be sent over a telegraph wire and reproduced at the receiving station with all their distinctive characteristics.

I have had occasion, in previous articles on the synchronous-multiplex system, to call attention to the fact that the synchronous division of an ordinary telegraph wire into a number of parts, would eventually be applied to the transmission of fac-simile despatches. I have to-day received from Mr. Delany copies of the first fac-simile transmission with a crude experimental apparatus, which is herewith reproduced.

Although other systems of fac-simile transmission have been tried, and fac-simile dispatches have been sent and successfully reproduced, yet when but a single wire was employed, the time required for the transmission was so protracted, and the uncertainty of correct reproduction so great, that such systems of transmission could never come into actual commercial use.

Mr. Delany's system, however, differs from the preceding in that it insures speed and certainty of correct reproduction. By means of the application of his synchronous system an area of twelve square inches can be covered in one minute by the use of a single wire.

The many uses of this system of fac-simile transmission can scarcely be properly appreciated at this time; for, notwithstanding the comparatively coarse lines that are so evident in the specimens annexed, yet with more carefully prepared apparatus, constructed for actual use, we do not doubt but that Mr. Delany will be able to transmit portraits, and other similar work equal in fineness to the ordinary wood-cut, so that criminals may be readily intercepted in their flight by the telegraphing of their portraits; or, in times of war, maps showing the movements of armies, sketches of fortifications and works may be trans-

mitted; or the illustrated papers may be furnished, telegraphically, with sketches of disasters, at the same time that particulars of the same are being transmitted to them.

An evident advantage of such a system of telegraphic transmission is in the readiness with which it can telegraph in any language, even Chinese, for instance.

CENTRAL HIGH SCHOOL,
PHILADELPHIA, February 20, 1885.

CORRESPONDENCE.

AN INTERESTING AND SATISFACTORY EXPERIMENT. — PUMPING MOLASSES.—The Grocers' Sugar House (proprietor George E. Bartol), situated on Passyunk road near Washington avenue, at a distance of 6,600 feet from its wharf, foot of Reed street, on the Delaware, requires in its business 130 hogsheads, or 17,500 gallons of imported molasses daily. Heretofore it has been hauled by trucks at considerable expense as well as much injury to street pavements. The great success in pumping oil long distances determined Mr. B. to make the trial on molasses, although the article to be pumped was very different in character.

He decided to lay a three-inch wrought iron pipe which, in the distance named, has an elevation of twenty-three feet and makes five right-angle bends. The operation is as follows: the hogsheads of molasses are emptied at the wharf into a large iron tank, connected with which is a Blake steam pump, having a steam cylinder of fourteen inches diameter and a pump of five inches diameter, both twelve inches stroke. This pump discharges into the three-inch wrought iron pipe before mentioned. The density of the molasses varies with the temperature of the atmosphere, and at times it is necessary to heat it to a temperature of 110 degrees, and in some cases a little water has to be added. The pressure on the pump is not allowed to go beyond 400 lbs. to the square inch, and it is rarely that it reaches that, and it does not go below 250 lbs. The average daily work—of 17,500 gallons, as before stated—requires twenty-two double strokes of the pump per minute, delivering 2,000 gallons per hour; the difference between the capacity of the pump at that velocity and the amount of molasses actually delivered is ·10 per cent., showing that, owing to the density of the molasses, the pump does not fill to its full capacity.

After being in operation 18 weeks, it is demonstrated that all of the molasses emptied at Reed street wharf is delivered at the sugar house, also that no injury is done to the molasses by being pumped that distance under pressure. The pipe was laid and pump erected under the immediate supervision of Mr. Rafael Estrada, an experienced engineer, who is superintendent of the sugar house. B. H. B.

Committee on Publication of Franklin Institute, Philadelphia:

GENTLEMEN:—In the JOURNAL OF THE FRANKLIN INSTITUTE for December last, appeared a reprint from *Mechanics* for November, of an article

by Mr. C. E. Simonds, of East Cambridge, Mass., on the subject of standard dimensions for the heads and nuts of bolts. This extract was followed by a reply from Mr. Coleman Sellers.

Mr. Simonds, in the course of his remarks, alludes, with some dissatisfaction, to the remarks on this subject given in a recent edition of "Trautwine's Civil Engineer's Pocket Book," and I, therefore, take occasion to say that some months ago I rewrote the remarks on this subject for the forthcoming edition, putting them, as I believe, in accordance with the present state of the case.

The amended article reads as follows:

BOLTS, NUTS AND WASHERS.—The following dimensions for bolts and nuts were proposed by Mr. Wm. Sellers and adopted by the Franklin Institute, of Phila., as a standard, in 1864, and by the U. S. Navy Dept.,* in 1868. They have been adopted by the principal machinists of the country, and are known as "Franklin Institute Standard" or "Sellers" dimensions. The angle a, Fig. 1, between the two sides of a thread, is 60°. w is the width (measured lengthwise of the bolt) of the flat top and bottom of each thread. N is the number of threads per inch of length of screw.

D In.	d In.	w In.	N	D In.	d In.	w In.	N	D In.	d In.	w In.	N	D In.	d In.	w In.	N
¼	·185	·0062	20	1	·837	·0156	8	2	1·712	·0277	4½	4	3·567	·0413	3
5/16	·240	·0074	18	1⅛	·940	·0178	7	2¼	1·962	·0277	4½	4¼	3·798	·0435	2⅞
⅜	·294	·0078	16	1¼	1·065	·0178	7	2½	2·176	·0312	4	4½	4·028	·0454	2⅝
7/16	·344	·0089	14	1⅜	1·160	·0208	6	2¾	2·426	·0312	4	4¾	4·256	·0476	2⅝
½	·400	·0096	13	1½	1·284	·0208	6	3	2·629	·0357	3½	5	4·480	·0500	2½
9/16	·454	·0104	12	1⅝	1·389	·0227	5½	3¼	2·879	·0357	3½	5¼	4·730	·0500	2½
⅝	·507	·0113	11	1¾	1·491	·0250	5	3½	3·100	·0384	3½	5½	4·953	·0526	2⅜
¾	·620	·0125	10	1⅞	1·616	·0250	5	3¾	3·317	·0413	3	5¾	5·203	·0526	2⅜
⅞	·731	·0138	9									6	5·423	·0555	2¼

Fig. 1

Rough heads and nuts. $X = 1\frac{1}{4}D + \frac{1}{8}$ inch. H (in *head*) = ⅔X. H (in *nut*) = D.
Finished heads and nuts. $X = 1\frac{1}{4}D + \frac{1}{16}$ inch. H (in *head*) = H (in *nut*) = $D - \frac{1}{8}$ inch.
In the "Whitworth" (English) standard thread, the angle a, Fig. 1, is 55°. The tops and bottoms of the threads are rounded, instead of flat, as in the American standards. The number (N) of threads per inch is the same as above for diameters of bolt up to 3 in., except for D = ½ inch, where N = 12.

Figs. 2

* Except that the Navy Department uses, *for both rough and finished heads and nuts*, the dimensions given above for *rough* heads and nuts. The standard of the Navy Department is known as "United States Standard."

Yours very respectfully,

JOHN C. TRAUTWINE, JR.

PHILADELPHIA, *January* 23, 1885.

SOLAR PHENOMENA IN SWITZERLAND.—The reddish limb, by which the sun was often surrounded during the past summer, was very brilliant among the high Alps, and often approached a silvery whiteness near the sun, into which orange or violet tints were blended from a large exterior reddish corona, the limits of which were ill-defined. Beyond the corona, for a considerable distance, the sky was of a much darker blue than usual. —*Comptes Rendus*, Aug. 11, 1885. C.

Book Notices.

THE MODERN HIGH EXPLOSIVE. By Manuel Eissler. New York: John Wiley & Sons. 8vo, pp. xi + 388.

This book is a descriptive history of "nitroglycerin and dynamite, their manufacture, their use, and their application to mining and military engineering; pyroxylin, or gun-cotton; the fulminates, picrates and chlorates, also the chemistry and analysis of the elementary bodies which enter into the manufacture of the principal nitro-compounds." It is a satisfactory and interesting work as regards the treatment of the application of explosion to engineering operations, and at the same time an unscientific and faulty compilation of the chemistry of the subject. Especially is to be condemned the indiscriminate use of nearly all possible synonyms used in the chemical nomenclature of explosive compounds. These inequalities are probably to be attributed to the fact that the subject is treated from an engineer's standpoint.

A large portion of the book is made up of *literatim* quotations, properly credited, from the works of Abel, Drinker, Berthelot and Mowbray.

Apart from its somewhat questionable scientific value, this treatise will prove interesting and useful in its information of the extended and varied uses to which dynamite and nitroglycerin are now habitually applied. Some of the statements are really surprising: "At Smartsville, in California, it is almost a daily occurrence to fire blasts where twenty thousand, thirty thousand, and even fifty thousand pounds of explosives are burnt in one charge." Limestone quarries are mentioned where twenty thousand pounds are fired at one blast. The description of the applications of explosives to agriculture, tunnel-driving, channel deepening, pile-driving, etc., are no less entertaining, and will well repay a perusal of Parts II and III of the book, which is clearly printed on good paper.

A TREATISE ON ORE DEPOSITS. By J. Arthur Phillips, F.R.S., V.P.G.S., M. I. C. E., etc. With numerous illustrations. London: Macmillan & Co., 1884. For sale by J. B. Lippincott & Co., Phila.

This book may be said to give among the first visible signs of the change in the direction of English scientific method in matters relating to applied geology and mineralogy, which has nevertheless been apparent for some years to those whose studies brought them much in contact with the outer British pickets (so to speak) on these lines of investigation. For many years England monopolized the leadership in all applications of science to the arts; and in no cases more markedly than in metallurgy and mining.

This was not because other nations had not made great progress in these arts, but partly on account of the greater difficulties of an interchange of experiences of the more important manufacturers in different countries. What would once have been thought an accomplishment of a high order, viz.: the ability to read one or more foreign tongues with facility, is now expected of every beginner; and, more than this, the ability and desire to

profit by the results of one's foreign rivals are almost universal. This is as true of science as of trade. So that in spite of the indifference with which English scientific men professed to regard the improvements in the methods of attacking mining problems by building up the science of petrography (an improvement almost wholly due to the Germans) the advanced minds in England have not only accepted the new method but also improved it. This is apparent in the work before us on every page, and, indeed, in the first line of the preface, where the author pays a graceful tribute to the distinguished von Cotta and by inference to his American translator, Mr. Prime. The willingness of Englishmen to acknowledge merit in works published in America is not so venerable a characteristic as to be, of itself, entirely devoid of significance.

The book is divided into a general and a special part; the first treating of ore deposits in the abstract and containing much matter, both as illustration and as text, which has never before been printed, and which is admirable.

This material is taken as well from foreign as from English sources, and shows both familiarity with the literature and good judgment in the selection of examples.

The second part deals with the actual ore deposits of the different countries of the world beginning, of course, with England.

The first part takes 106 pages, followed by two very valuable pages of general conclusions. In these latter it is noteworthy to find an Englishman so far severing himself from the traditions of his countrymen as to acknowledge (p. 106) that there is no sharp division possible between "bed-veins" and "fissure-veins."

The mining world has been so long held in thrall by this kind of hair-splitting, that it is a great relief to find it ignored in an English work of authority. A previous part of the book, viz.: the discussion of the influence of the country rock upon veins, deserves even higher praise, and is a contribution of permanent value to the literature of economic geology.

The subject is first considered statistically, and then under the head of the "Genesis of Mineral Veins," a bibliographical notice of the opinions held up to the time of (and including) Werner, leads to the categorical discussion of all the modern theories which our author deems worthy of mention. These are seven, viz.: 1, Contemporaneous Injection; 2, Igneous Injection; 3, Electric Currents; 4, Aqueous Deposition from above; 5, Sublimation; 6, Lateral Secretion; 7, Ascension. The importance of 6 is well brought out in its fuller treatment; and the contributions of Sandberger and Forschammer are fairly acknowledged.

In this part, too, we notice several sketches from nature by that excellent observer, Clement LeNeve Foster, H. M. Inspector of Mines in Wales. In the second part, Cornwall, of course, claims the first as well as the largest part of the description of England's mining districts, in fact more than the third of all those of the United Kingdom combined. France is finished in 18 pages, while Cornwall required 38; but this is less the result of national prejudice than a desire to avoid repeating what has already been used for the purposes of illustration in the citation of English localities, which, as a general rule, are more instructive. Belgium claims 2

pages; the German Empire but 52; Austria-Hungary, 22; Italy, 12; Greece, 8; Spain, 10; Portugal, 4; Scandinavia, 12, and Russia, 10.

The Indian Empire occupies 25 pages; the Australasian colonies, 65; Africa must get along with 4 pages; while the Land of Freedom is complimented by having 57 pages dedicated to its mining affairs (more, even than Cornwall), and Canada receives 25 pages. All South America is comfortably stowed away in 9 pages.

The book will be almost a necessity to every instructor in the branches with which it deals, while it will be indispensable to the field geologist and mining engineer who has the ambition to keep abreast of the progress in his profession. P. F.

THE STEAM ENGINE INDICATOR AND ITS USE.—By W. B. Le Van. Van Nostrand's Science Series.

Judging this little book in its relation to the numerous class aspiring to become familiar with the Steam Engine Indicator, its usefulness is undeniable; for it contains all the information which can be given to this class, composed principally of men to be found in the workshop and in the engine-room.

The author has premised wisely a number of popular historical notions bearing on the mechanical equivalent of heat, and properties of steam, which, although not absolutely necessary for the understanding of the subject, are well designed to elevate the working mechanic, and to inspire him with respect and gratitude for those who have devoted, and for those who are devoting, their lives to the cause of science. L. d'A.

INFLUENCE OF LIGHT ON TISSUES WITHOUT CHLOROPHYLL.—G. Bonnier and L. Mangin, in their physiological studies of mushrooms, investigated the influence of light upon respiration. A new series of experiments upon the respiration of tissues without chlorophyll, has led them to the following conclusions:

I. Solar light, direct or diffused, other conditions being equal, attenuates more or less the intensity of respiration.

II. For the same individuals, the ratio of the volume of carbonic acid emitted to the volume of oxygen absorbed is the same in light and in darkness.—*Comptes Rendus*, July 21, 1884. C.

INFLUENCE OF INTELLECTUAL WORK ON THE ELIMINATION OF PHOSPHORIC ACID.—A. Mairet has made numerous observations upon the modifications which are produced by intellectual labor in the elimination of phosphoric acid, and formulates the following conclusions: 1. Phosphoric acid is intimately connected with nutrition and with the activity of the brain. The brain, when acting, absorbs carbonic acid united with alkalies, and gives out phosphoric acid united with earths. 2. Intellectual labor slackens the general nutrition. 3. In the excretions, intellectual labor diminishes the amount of phosphoric acid which is united with alkalies and diminishes the amount which is united to the earths.—*Comptes Rendus*, Aug. 11, 1884. C.

Franklin Institute.

[*Proceedings of the Stated Meeting, held Wednesday, February* 18, 1885.]

HALL OF THE INSTITUTE, February 18, 1885.

MR. WILLIAM P. TATHAM, President, in the Chair.

Present, 103 members, and 3 visitors.

Five persons were reported as having been elected members at the last meeting of the Board.

The unanimous election of MR. HERBERT L. HEYL, as Actuary, in place of Mr. D. S. Holman, who declined a re-election, was reported by the Secretary.

Mr. Barnet Le Van read the paper of the evening on "The Economy in the Use of High-Pressure Steam." The paper was discussed by Messrs. Orr, Bilgram and the author, and, together with the discussion, has been referred to the Committee on Publication.

The Secretary's report embraced comments on the World's Fair at New Orleans; the last annual report of the Commissioner of Patents; the failure of the Nicaragua Treaty and its influence on the projected canal across that portion of the Isthmus; the recent disasters from the explosion of natural gas in Pittsburgh, and the necessity of taking stringent measures to provide against them; and the description of several interesting novelties. Among these there was shown on the screen and described, a projected tower 100 meters high, which it is proposed to erect in Paris, in connection with the Universal Exposition of 1889, which it is proposed to hold in that city. The design of this tower is by M. G. Eiffel, and its details are described in the *Annales des Travaux Publics*, November, 1884. A view of a new rotary stone-cutting machine, having some novel features was shown. The machine has a circular cutting-disk furnished with insertable teeth; the disk is driven from the *periphery*, being simply journaled loosely on the axle; is fed slowly; and makes its cut backwards and upwards. This machine is the invention of Messrs. John H. Crump and Richard Brereton, of Philadelphia, and is found specially serviceable for quarrying slate. A detailed description of this machine has been referred for publication.

The Secretary described, on behalf of Mr. Russell Thayer, C. E., of Philadelphia, a plan of avoiding the explosion of oil tanks from lightning, by "introducing steam into the tank between the roof of the same and the surface of the oil." The theory of the author is that such explosions are caused by concussion, and that if the gases generated from the oil are saturated with water vapor, such mixture of gas and water vapor is not explosible by concussion or otherwise.

There were also shown, on behalf of Messrs. Jas. W. Queen & Co., several analytical balances of improved construction, and of great delicacy and accuracy; and a miner's safety-lamp, embodying several substantial improvements.

A new method of producing manifold copies of writing was shown and described. It is called the "Cyclostyle," and permits of the reproduction of several thousand permanent impressions in black ink.

The process is briefly as follows: A sheet of oiled, or tracing, paper is fixed in a rectangular frame, the bed of which is a smooth surface of metal. The circular or other matter is then written on this sheet of paper with the cylostyle pen. This consists of an ordinary wooden holder, at the end of which is a small spindle at right angles with the holder, on which spindle is pivoted a minute circular disk of platinum, with a sharp milled edge. This wheel revolves in the direction of the writing and cuts a stencil in the oiled paper. The copies produced closely resemble ordinary writing, the minute dots appearing to the unaided eye as a continuous line.

Immediately after the writing is finished, the printing may, if desired, be commenced. Any paper may be used for printing, though unglazed paper is preferred for the reason that it dries more rapidly than one that is highly glazed. The printing is done by laying the sheet to be printed on the metal bed, placing the stencil down over it and passing an inking roller over the face of the stencil. The stencil is then raised, the printed impression removed, a fresh blank sheet substituted, and the operation is repeated.

Any error can be rectified by simply rubbing the stencil with the thumb nail, when the holes will be found to close and any other word or words can then be written in substitution. The original may be left for any length of time, and further copies taken when required. Copies can be obtained at the rate of several hundred per hour, and it is said that as many as 2,000 copies can be made from a single stencil.

The President named the following standing committees for the year:

Library.—Charles Bullock, J. Howard Gibson, Frederick Graff, Wm. D. Marks, S. H. Needles, Isaac Norris, Jr., A. E. Outerbridge, Jr., T. D. Rand, Charles E. Ronaldson, Lewis S. Ware.

Minerals.—Clarence S. Bement, Persifor Frazer, F. A. Genth, Edwin J. Houston, George A. Koenig, Otto Lüthy, E. F. Moody, H. Pemberton, Jr., Theo. D. Rand, Wm. H. Wahl.

Models.—Edward Brown, H. L. Butler, C. Chabot, L. L. Cheney, N. H. Edgerton, John Goehring, Morris L. Orum, Chas. J. Shain, John J. Weaver, S. Lloyd Wiegand.

Arts and Manufactures.—J. Sellers Bancroft, George Burnham. Cyrus Chambers, Jr., George V. Cresson, Wm. Helme, Wm. B. Le Van, Alfred Mellor, J. W. Nystrom, Henry Pemberton, John J. Weaver.

Meteorology.—David Brooks, J. B. Burleigh, William A. Cheyney, J. A. Kirkpatrick, F. B. Maury, Isaac Norris, Jr., Hector Orr, Alex. Purves, Wm. H. Wahl.

Meetings.—Chas. H. Banes, Hugo Bilgram, A. B. Burk, G. M. Eldridge, Fred'k Graff, Henry R. Heyl, Washington Jones, H. Pemberton, Jr., E. Alex. Scott, Coleman Sellers.

After the transaction of some formal business, the meeting was adjourned.

WM. H. WAHL, *Secretary.*

LIST OF BOOKS

ADDED TO THE LIBRARY FROM JULY, 1884, TO JANUARY, 1885.

Abbott, Arthur V. Improvements in Methods for Physical Tests. American Institute of Mining Engineers. 1884. 8vo, pamphlet. Presented by the Institute.

Abbett, Leon. Governor of New Jersey. Inaugural Address of 1884. Camden, 1884. 8vo, pamphlet. Presented by His Excellency.

Abel, Prof. F. A. Electricity Applied to Explosive Purposes. Ordnance Notes, No. 357. Washington, 1884. 8vo, pamphlet. Presented by Ordnance Department.

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Académie des Sciences. Institut de France. Recueil de Mémoires, Rapports et Documents relatifs a l'observation du passage de Vénus sur le Soleil. Tomes 1 to 3, in 6 parts. Part 2, Vol. 3 wanting. Paris. Firmin-Didot et Cie. 1877-1882. 4to. Presented by the Académie Royale des Sciences de l'Institut de France.

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Académie Royale des Sciences de l'Institut de France. Tables Génerales des mémoires. 1816-1878. Paris. 4to. Presented by the Académie Royale des Sciences de l'Institut de France.

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Agricultural and Mechanical College of Mississippi, Fourth Annual Catalogue. Starkville. 1884. 8vo, pamphlet. Presented by the College.

Agriculture and Public Works of the Province of Quebec, General Report of the Commissioner. 1883. Quebec, 1884. 8vo, unbound. Presented by the Commissioner.

Alabama State Agricultural Experiment Station. Circulars of the Commissioner and Bulletin. Nos. 2, 3, 4 and 6. Auburn, 1884. Presented by Wm. C. Stubbs, State Chemist.

Almanac, Nineteenth Century. A Complete Calendar from 1800 to 1900. Philadelphia, 1884. 16mo. Presented by Dr. Wm. H. Wahl.

American Academy of Arts and Sciences. Proceedings from May to December, 1883. Boston, 1883. 8vo, unbound. Presented by the Academy.

American Academy of Arts and Sciences. Proceedings from May 1883 to May 1884. Boston, 1884. 8vo, unbound. Presented by the Academy.

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American Institute of Mining Engineers. Proceedings of the Annual Meeting in Cincinnati. 1884. 8vo, pamphlet. Presented by the Institute.

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Archæological Institute of America. Bulletin of the School of Classical Studies at Athens. Boston, 1883. 8vo, pamphlet. Presented by John Williams White.

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Bond, Geo. M. Standards of Length and their Subdivision. Franklin Institute. Philadelphia, 1884. Pamphlet, 8vo.

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1885. "Novelties" Exhibition 1885.

The Franklin Institute of the State of Pennsylvania
for the Promotion of the Mechanic Arts.

Saturday
Oct. 31
to Close

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

To Open
Tuesday,
Sept. 15.

To Close
Saturday,
Oct. 31.

PHILADELPHIA, March, 1885.

The Franklin Institute herewith respectfully invites the attention of Manufacturers, Inventors, and others interested in the progress of the Arts and Manufactures to the fact that, in conformity with the action of the Board of Managers, taken January 14, 1885, an Exhibition will be held, under the direction of the Institute, in the Exhibition Buildings at Thirty-second and Lancaster Avenue, in the Autumn of the present year.

The projected enterprise will be known as the

"NOVELTIES" EXHIBITION,

and will be restricted, as its title indicates, to the exhibition of such recent discoveries and inventions in the Sciences, Arts and Manufactures as, in the judgment of the Exhibition Committee, are worthy, by reason of merit, to be admitted.

The selection of the subject of the forthcoming Exhibition is due, in a large measure, to the experiences of the Committees in charge of the arrangements for the late, highly successful, "International Electrical Exhibition," which indicate that a suitable opportunity of advantageously exhibiting, in collective form, the most recent discoveries, inventions and improvements in the various Arts and Sciences will be warmly welcomed by those directly interested in bringing them under public observation.

By the title chosen for this Exhibition, it will be understood that, while it will not be confined to any special subject or class of subjects, it is not intended to be a general exhibition of the arts and manufactures, such as was last held under the patronage of the Franklin Institute in the year 1874. It is the conviction of the Board of Managers that such Exhibitions, in view of the great development and variety of the industries in our day, should properly be relegated to the World's Fairs. While, therefore, they will allow the widest latitude in the character of the objects admitted, the aim and intention of the Committee, in organizing the forthcoming Exhibition, will be, to confine the same to such as shall possess, first, the qualification of "Novelty," and, second, the qualification of "Merit," which shall redeem them from triviality.

The Board of Managers have decided, in connection with the "Novelties" Exhibition, to return to their time-honored custom of awarding Medals and Certificates, as tokens of special merit, in the belief that this plan will have the approval of the great majority of exhibitors.

With this general explanation of their intentions, the Board of Managers of the Franklin Institute cordially invite the personal interest and coöperation of Men of Science, Manufacturers and Inventors, in making the "Novelties" Exhibition of 1885, successful. The reputation of the Institute and the prestige which the admirable Exhibition of 1884 has given it, afford to intending participants the best assurances that the forthcoming Exhibition will be in all respects worthy of its sponsor, and that its pledges to all who take part in it, will be faithfully redeemed.

The "Novelties" Exhibition will be opened on *Tuesday, September 15*, and will be closed on *Saturday, October 31, 1885*.

Applications for space may be made at once, and will be considered in the order of their reception.

Copies of the Rules and Regulations, Blank Forms of Application for Space, and all needful information, may be obtained by addressing "The Committee on Exhibitions," Franklin Institute, Philadelphia, U. S. A.

By order of the Board of Managers.

HENRY R. HEYL,
Chairman Committee on Exhibitions.

W. P. TATHAM, *President.*
WILLIAM H. WAHL, *Secretary.*

1885.—"Novelties" Exhibition—1885.

—OF—

The Franklin Institute of the State of Pennsylvania
for the Promotion of the Mechanic Arts.

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VOL. CXIX. APRIL, 1885. No. 4

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ON THE MODIFICATIONS OF TENSILE STRENGTH AND DUCTILITY WHICH IRON AND STEEL UNDERGO WHEN HEATED TO BETWEEN CERTAIN TEMPERATURES.

[Translation by Chief Engineer Isherwood, United States Navy, of the paper on that subject read by Engineer-in-Chief E. Cornut of the North of France Association, before the 7th Congress of the Engineers-in-Chief of the Associations of Proprietors of Steam Boilers, held at Bordeaux, France, on the 10th, 11th and 12th September, 1882.]

[NOTE BY TRANSLATOR.—The influence of temperature on the ductility, elasticity, and cohesive strength of wrought-iron and of steel, though of great importance in the industrial arts, has received so little attention, owing doubtless to the difficulty and cost of the investigation, that any new experimental facts on the subject have exceptional value, particularly as plate steel in the various modifications of iron which bear that name, is coming into general use for boilers, and for the hulls of vessels, I have therefore translated the following paper read by Mr. Cornut, the distinguished Engineer-in-Chief of "The North of France Association," before the 7th Congress of the Engineers-in-Chief of "The Associations of the Proprietors of Steam Boilers," held at Bordeaux, France, on the 10th, 11th and 12th of September, 1882, which contains some valuable facts and inferences concerning this subject.

In the paper referred to, is given the true explanation of the apparently abnormal result that iron and steel increase in cohesive strength by increase of temperature up to about 550 degrees Fahrenheit, instead of diminishing, as do all other substances. The rupturing strain, it is important to observe, being referred to the original cross section of the specimen tested and not to the cross section at the instant of fracture. That such is the effect has long been known, but not the cause producing it, namely, the